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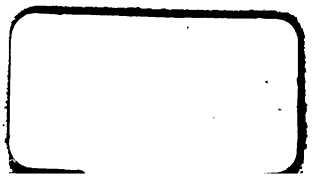

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MODERN ELECTRIC

RAILWAY MOTORS

A Discussion of Current Practice in Electric Railway Motor Construction, Maintenance, and Repair

BY

GEORGE T. HANCHETT, S. B.

Member of the American Institute of Electrical Engineers

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PREFACE.

In presenting this work for public consideration the writer desires to impress upon the reader that it is intended more particularly for those who have just entered or are about to enter active work in the electric railway field. The object of the book, in short, is to show how electric railway motors are made to-day and why they are made so.

The electric railway field is one which is subject to rapid changes of method, and even during the process of preparing this short work for the press, it has been necessary to make substantial changes in text to bring it down to date. Ideas and improvements in electric railway work are occurring almost daily, and what is good practice to-day is history to-morrow, a fact which the reader should bear in mind.

The work is largely of a descriptive character. A few general principles are laid down, illustrated by present and past practice and comparisons of merits. For the benefit of those who are actively employed in handling or repairing railway motors, a chapter on that subject has been added, while for those whom the subject interests from the designer's standpoint, the concluding chapter of the book has been prepared.

With the exception of the final chapter the book can be easily read and understood by anyone who has had a thorough grounding in Ohm's law. For those who wish to acquire general information about electric rail-

way motors, it is hoped that this work will prove useful.

In closing, the author desires to thank the various electrical manufacturing companies which have so generously responded to his requests for data, without which success could hardly be expected for the work. In this connection it may be stated that the table of dimensions and data accompanying this book has been revised and corrected by the engineering forces of the manufacturers whose products are represented, and may therefore be relied upon. Thanks are also due tc the publishers, who have co-operated with the author in the endeavor to make this work attractive in appearance and otherwise worthy of the class of readers for whom it is intended.

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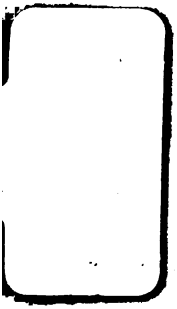

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considerations are the only ones that enter. Chief among these are the following:

1. The field magnet is the heaviest part of the motor, and hence, to effect a reduction in the weight of the motor as a whole, careful attention should be given to the form and design of a field magnet.

2. The field excitation must take as little energy as possible; therefore a form that has much magnetic leakage or that for other reasons requires excessive energy should be avoided.

3. The field magnet should be of such form that it can be easily modeled into an iron-clad construction that will protect both armature and field coil from dust, water, and mechanical damage.

4. It must be arranged so that the motor casing can be easily opened for inspection and repair.

5. The field must be both magnetically and mechanically balanced so as to divide the work evenly between the sections of the armature and avoid sparking, and also to distribute the strain equally on the bearings of the motor.

6. The diameter of the motor is usually limited by that of the car wheels, and, under ordinary conditions, must necessarily be somewhat less; hence, if the motor is to be very powerful, this consideration will play a most important part in the selection of the form of field magnet.

It is now well to discuss the types of field magnets that have been used in railway motor design, and to show in what degree they fulfill the practical requirements just recited. The reader is referred to the diagrams, Figs. 1 to 8 inclusive. In these sketches are shown the exciting coils and the iron paths provided for the lines of force that are produced by the coils, and lastly the pole pieces that distribute the magnetism

over the proper zones of the armature. It is to be remembered that these diagrams are by no means proportional drawings, but have for their object merely the illustration of principle.

Two types of poles are used in railway motors. A pole that carries a coil is called a salient pole, and one which is formed by the return flux of a coil surrounding a salient pole is called a consequent pole. A ma-

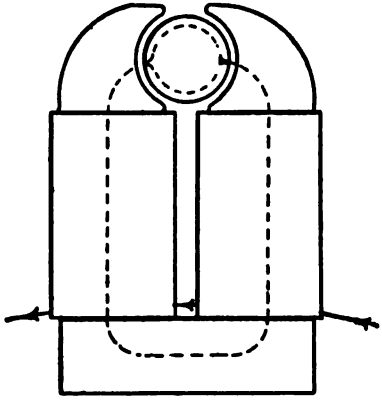

Fig. 1.—Simple Bipolar Horseshoe.

chine may have its poles all salient, or half salient and half consequent.

Fig. 1 shows the common horseshoe type of field magnet in which both poles are salient; as this form is never used in present practice, because of its exposed construction, the only excuse for giving it a place in this treatise is that it was the first successful form employed in a railway motor. It was used by Sprague, the Thomson-Houston, and Westinghouse companies in the No. 6, F 30, and No. 1 motors, respectively. Fig. 2 shows a form used in experimental motors and to some extent abroad, but it has never been adopted to any considerable extent in American

practice. Being partially iron-clad, this motor was quite successful. It has two salient poles and two magnetic circuits, as shown by the dotted lines, and the field is very symmetrical. This motor was inconvenient to open because the dividing line of the field magnets had to be vertical instead of horizontal. It would have been very easy to spread out the re-

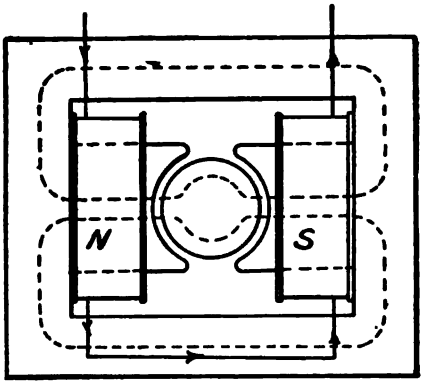

Fig. 2.—Internal Salient Bipolar Horizontal.

turn magnetic circuits and make a closed casing over the wire-wound parts of the machine, but this was never done.

By turning on end the type shown in Fig. 2, and slightly modifying it, we have the magnetic circuit shown in Fig. 3, which was first used on the S. R. G. (single-reduction gear) motor of the Thomson-Houston Company. This motor was the first successful single-reduction motor, and was very much appreciated by railway men. As will be seen, the coils of the field partially protected the armature. Not a few roads are using S. R. G. motors to-day, and as these motors have not been manufactured for some years, it can be seen that they have been wonderfully durable and efficient for a type that was so largely exposed. This ma-

chine has an exceptionally well-balanced field and has a double-return magnetic circuit. It can be divided

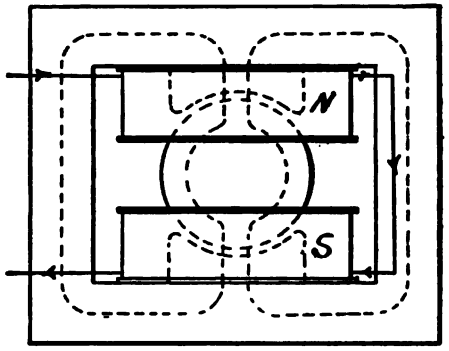

Fig. 3.—Internal Salient Bipolar Vertical.

horizontally, and thus is exceptionally convenient, as compared with the earlier types.

From the S. R. G. motor we pass to the form of field magnet which was used on the W. P. (water

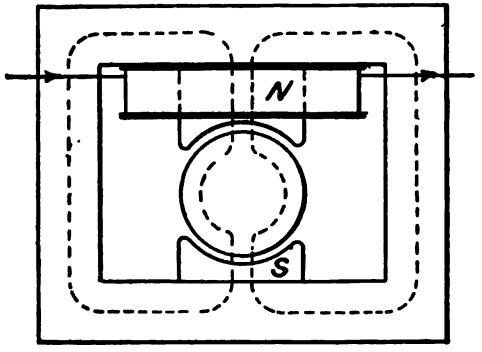

Fig. 4.—Internal Consequent and Salient Bipolar.

proof) 30 and 50. This machine (Fig. 4) has only one field coil, which is in the upper part of the casing, where dust and moisture would find it difficult to collect. It has one salient and one consequent pole. It

was built iron-clad, but not completely so, for semi-circular apertures were left in the upper half of the casing through which the commutator and brushes could be inspected. The simplicity which obtains in this type is at the expense of a balanced field; the salient pole is very much stronger than the consequent one and produces an upward pull on the armature, which, it was intended, would be counterbalanced by the weight of the latter. This counterbalancing action is only partial, with the result that the armature was very hard on the bearings. All of the troubles consequent upon uneven distribution of work in the armature were experienced. It remains to be said, however, that this type of field magnet was a great stride in advance of all practice up to that time, and that the motor is famous even to-day for its tremendous hauling powers. Many managers of railroads have said that it is the only motor that will act satisfactorily as a single equipment, and that even the most modern types are deficient in torque, when compared with the W. P. 50. The motor used considerable current, and having a very large armature carrying many conductors, the reasons for its powerful torque are apparent.

The next form to be discussed is that of Fig. 5. When turned on its side it represents the type used in the Edison General Electric motors. It has two salient and two consequent poles. The advantage of using the machine on its side was that the consequent poles could be made much shorter than the salient poles, and therefore the distance from the center of the machine to the lowest part was so short that a very powerful motor could be used without encroaching on the necessary clearance space between the casing and the roadbed. Owing to the fact that the machine can

be conveniently divided only along the line A B, it became difficult of inspection when used in such a position that this dividing line was vertical. For this reason, in succeeding types the machine was turned so that the dividing line became horizontal, in spite of the fact that the inherently long dimension of the

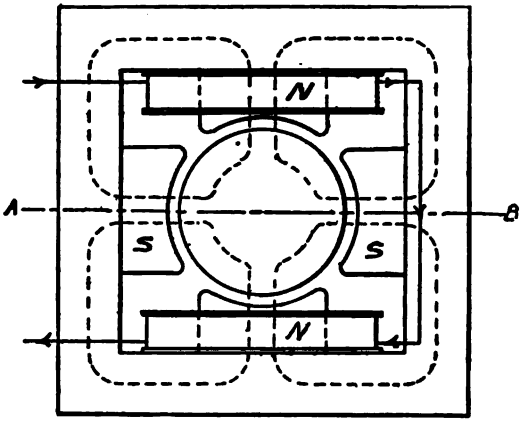

Fig. 5.—Internal Consequent and Salient, Four Pole.

motor now became the vertical one. The field of this motor is in mechanical balance, but as the salient poles are always stronger than the consequent ones, the magnetic balance is somewhat disturbed. Careful design has done much to make this difficulty practically *nil*. On these lines the well-known G. E. 800 motor was built and also the early Steel motor.

The type shown in Fig. 6 is that first used by the Westinghouse Company, and has since become universally adopted. All the poles are salient and it produces a remarkably symmetrical field. It can be conveniently divided along the line A B, and is a very desirable construction. It has, however, the complication of four field coils, so the choice between

the types shown in Figs. 5 and 6 is nearly an even thing, for each has advantages the other has not.

It remains to be said that four coils were cooler than two taking the same energy, on account of greater radiating surface.

Fig. 7 shows an adaptation of the Brush magnetic circuit as applied to electric railway motors. It will be

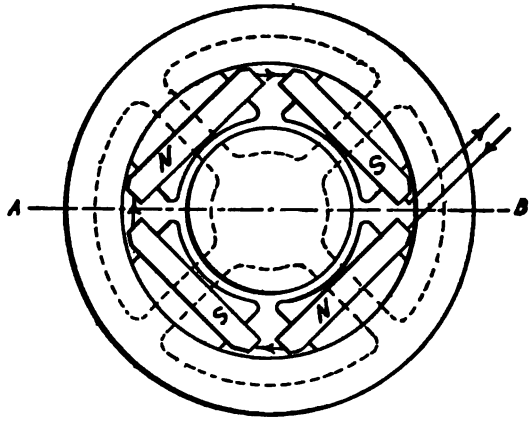

Fig. 6.—Internal Salient, Four Pole.

remembered that about the time of the appearance of this motor, in 1890, there were a great many manufacturers of dynamo-electric machinery in the country, and each had his own idea regarding the best form for field magnets. These ideas, in almost every case, were incorporated into electric railway motors where the manufacturing company attempted to compete in this field. This type was the result of such practice.

It can be easily seen that all of the types except that of Fig. 1 can be made iron-clad, and those of Figs. 5 and 6 were made completely so, access being obtained through suitable doors in the casings.

Fig. 8 shows another type of motor which was first introduced in railroad work by Professor S. H. Short.

It has six poles, and as the lower one is consequent, an extremely powerful motor can be built, in which the distance from center to base is a minimum. This was the final form of Professor Short's gearless motor, and was subsequently used with great success on the

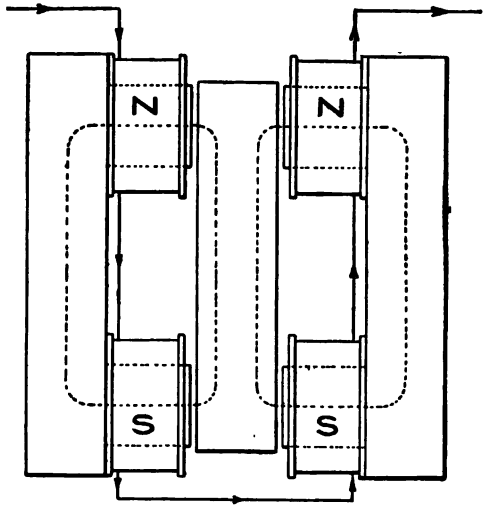

Fig. 7.—Brush Form of Field Magnet. Side Presentation.

Baltimore & Ohio electric locomotives. The three field coils surround three salient poles, the rest being consequent ones, and it would be hard to make a construction any simpler. Each of the magnetic circuits is so short that it can be readily designed so that the difference in strength between the salient and consequent poles is very slight indeed, and as their distribution about the armature is symmetrical, perfect mechanical balance is obtained.

It is interesting to note that Figs. 4, 5, and 8 represent the same class of field magnet, that is, the class having alternate salient and consequent poles, and that as the number of poles increases the field becomes

more symmetrical, also that after the bipolar form is passed, the trouble of mechanical unbalancing is done

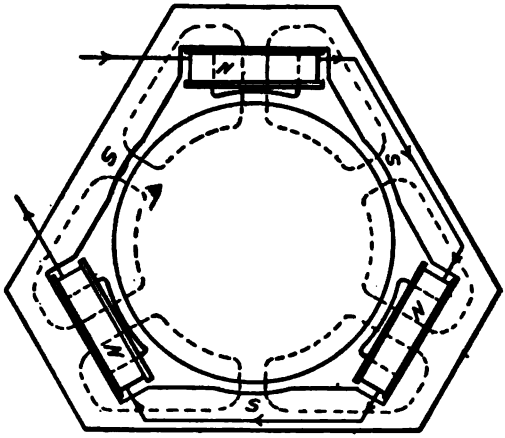

Fig. 8.—Internal Alternate Consequent and Salient, Six Pole.

away with. Similarly Figs. 2, 3, and 6 belong to the same class, all of the poles being salient.

With the exception of a few experimental types, electric railway motors are series motors, that is to

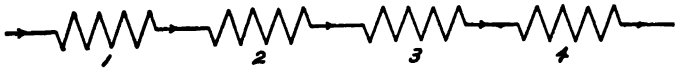

Fig. 9.—Simple Series.

say, the field coil is connected in series with the armature. It will be easily seen that the coils may be connected in series or in multiple with each other.

The forms of field magnets that have been shown have from one to four coils, and these are connected in different ways in practice. The method which is now almost universally used is to connect them all in series, as shown in Fig. 9. Then, if each coil has the same number of turns, magnetic balance is assured, for the ampere turns of each coil is the same. Con-

necting two coils in multiple has been used, but it is not so satisfactory, for the reason that even though the coils were of the same number of turns the conductivity of the copper might not be the same; the

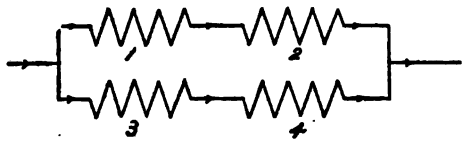

Fig. 10.—Multiple Series.

current would then divide unevenly between the two sets, thus producing an unbalanced field, where the form of the field magnet gave no excuse for other than a balanced one. The only reason for using this con-

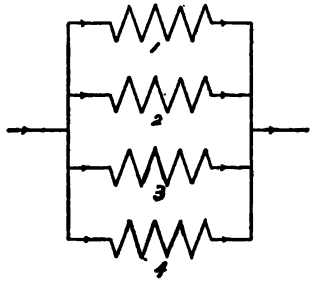

Fig. 11.—Multiple.

nection is that smaller wire may be used on the coils, and this in some cases might make the winding easier. It would also be possible to connect all of the coils in multiple, as shown in Fig. 11. This would be liable to result in even more unbalancing than that of Fig. 10, but the wire of each coil would be of one-fourth the section.

In some of the larger sizes of railway motors the field wire is as large as No. 0000, and a reduction to No. 3, B. & S., is a great advantage to the winder. It is possible, however, to wind the single spools with

four small coils and connect like coils on the different spools in series, and join the series of four in multiple. This will be almost as easy for the winder as the simple multiple connection, and will avoid unbalancing.

In some of the earlier American motors it was customary to bring out a terminal from an intermediate

Fig. 12.—Loop System.

point on the field winding, as shown in Fig. 12. In this way the main current could be sent through the whole or a part of the field coil and a regulation of speed could thereby be obtained. This has been abandoned in the later types, partly because good speed regulation can be obtained without its use, and partly because its application to multi-coil fields involves considerable complication.

CHAPTER II.

ARMATURE WINDING DIAGRAMS.

THE following experiment will be of great assistance in understanding an armature winding. Bend a wire of stout copper, as shown in Fig. 13, and sharpen the ends. Obtain a small dish,—a table butter dish will answer,—place the wire in it, and support the upper end of the wire by a stand, as shown in Fig. 14. Connect the stand to one terminal of a battery and connect the other terminal of the battery to a globule of mercury placed in the dish, thus making

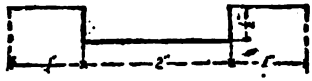

Fig. 13.—Experimental Armature.

a circuit through the wire. If this is properly done the wire will be delicately poised and easily revolved about the axis, C D. Procure a wooden block and on it mount a magnet, arranging its poles to surround the wire, as shown in the figure. We will then have a two-pole field and a single conductor so poised that if currents are properly directed through it it may be revolved under the influence of the magnetism. Let us suppose that the wire is opposite a north pole and that current is sent through it in an upward direction. The wire will rotate in the direction shown by the curved arrow till it reaches the south pole, when it will be found that if the rotation is to proceed, the current in the wire will have to be reversed. By appropriately

reversing the circuit as the wire turns, it may be made to revolve continuously, and if we could make the wire do it own reversing, we should have an electric motor.

Now, if instead of using a single wire we take a cylinder of wood or any convenient material and cover its periphery with wires closely laid together and parallel to the axis, it is obvious that if we place such a cylinder in a field having two or more poles, and so connect these wires that the current will always

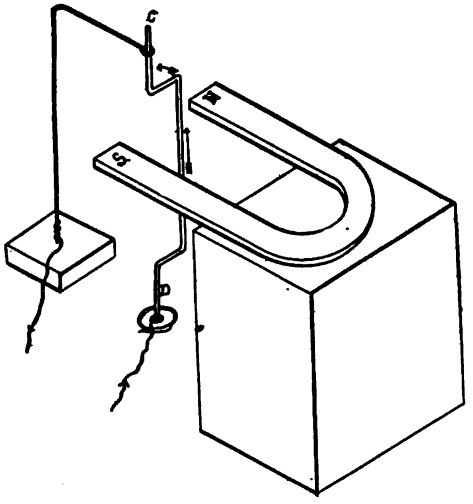

Fig. 14.—Experimental Motor.

flow in the proper direction in them as they pass under their respective poles, the joint action of all of these wires will produce a very much stronger rotative effort. If we make the cylinder on which these wires are placed of iron, the magnetic flux will be concentrated on the wires and will make the turning moment or torque still greater. This is the principle of every direct-current railway armature.

The experiment has shown that every active wire

in such an armature must have its current reversed as it passes from pole to pole, and therefore these wires must be suitably connected to a system of sliding contacts traveling under brushes which feed current to the armature. This will enable the necessary reversal to be automatically accomplished, and is also a means of supplying current to the revolving member.

It is further evident that for maximum effort all of the wires in front of the north poles must carry current in the same direction, say, up, and all in front of the south poles must carry current correspondingly down, no matter how fast the armature is revolving. Thus the sections of the armature opposite the polar faces divide the armature into alternate and equal sections of up and down currents. If therefore we can devise a system of wires and contacts such that, as the armature revolves under the brushes, it will present sections of its surface to the polar faces which always carry currents in the proper direction, the problem of designing a winding will have been solved.

It is evidently necessary for such a winding to be perfectly symmetrical, for having designed the winding so that the flow of current is correct for one position of the commutator under the brushes, it must be always the same, no matter how the armature is turned.

If we should attempt to trace an armature winding by an examination of the armature itself or by mere description, we should find it a puzzling, if not an impossible task. Some form of diagram must be used, and in this work the following will be adopted: We will consider the cylindrical surface of the armature with its wires to be stripped off and laid out flat, in much the same way as the bark from a birch tree would be stripped (see Fig. 15). To further render the

matter clear, such parts of the armature as are covered by the pole pieces will be designated by shaded rectangles. The cross-hatching on the north pole will be parallel to the slanting crossbar of the letter N. In addition to the developed diagram there is added an end view of each winding, which shows the end connections more clearly. It is but justice to say that

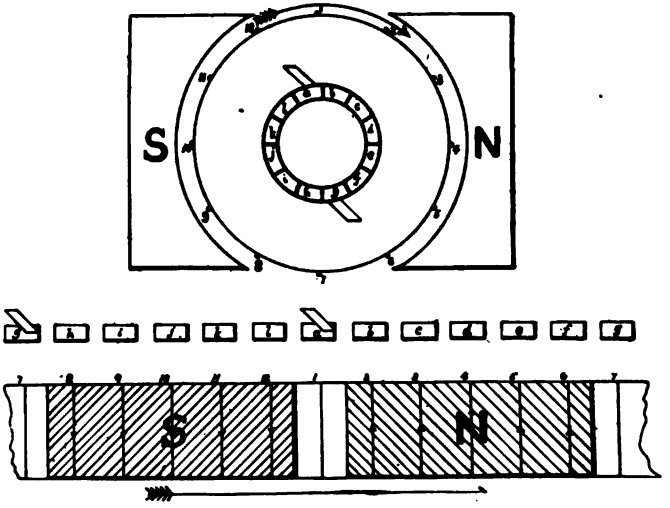

Fig. 15.—Proper Distribution of Conductors over Pole Pieces.

this method, which is without doubt one of the clearest of any, is due to Professor Sylvanus P. Thompson.

Before commencing a study of these diagrams it is well to say that the wires have been reduced to an absurdly small number for practical use, but by thus avoiding a multiplicity of lines the principle of the winding is more readily seen. It is conventional to call the straight wires on the surface of the armature directly under the influence of the polar faces, conductors, and the wires connecting these together, connectors. The conductors are active wires and the

connectors are the dead wires and should be as short as possible. Now, consulting Fig. 15, we have a problem the solution of which has been reached in many different ways. It is briefly how to connect the conductors to each other and to the commutator bars so that the current distribution shown by the arrows will always obtain, whatever the position of the commutator under the brushes.

The simplest solution is shown in Fig. 16. Here the connector joins opposite ends of adjacent con-

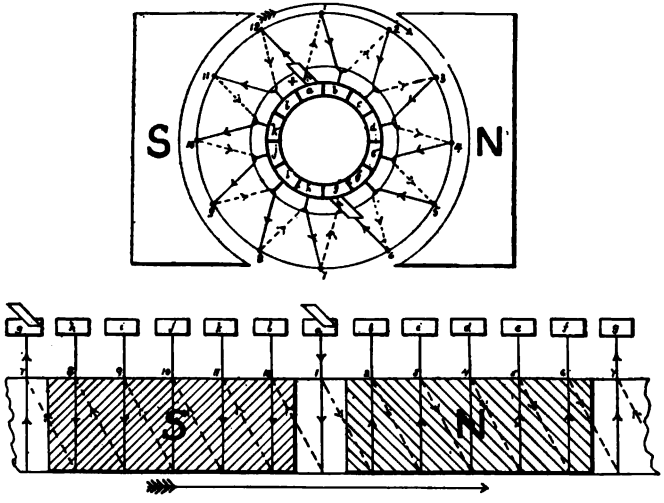

Fig. 16.—Ring Winding, Two Pole.

ductors and leads are brought down at equal intervals to the commutator bars. Tracing the current out from brush to brush, the directions will be seen to be correct, and as the system is symmetrical, any movement under the brushes will simply change the direction of the current in each wire as it passes from pole to pole, and thus prevent any change in the current distribution under the polar faces. It will at once be questioned

whether the connector carrying an equal and opposite amount of current should not neutralize the rotative effect of the conductor. This would certainly be the case if the connector were under the influence of the pole piece, but this influence it avoids by passing through a hole in the center of the core, which is really

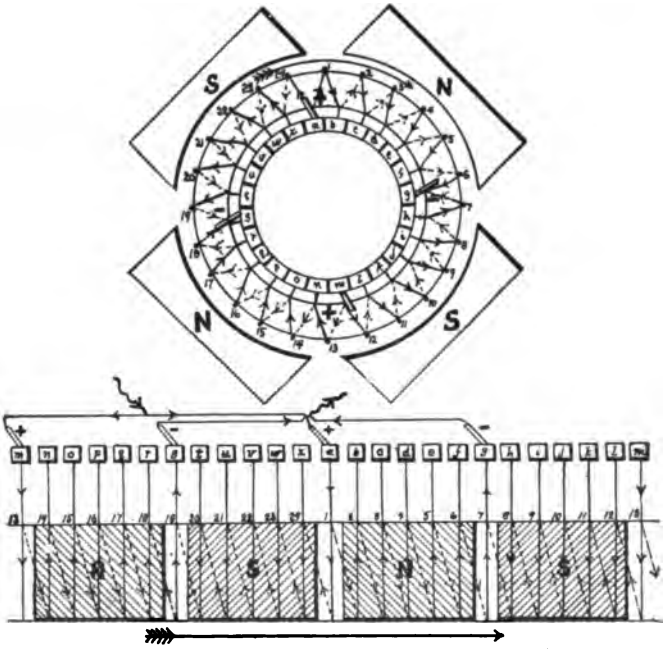

Fig. 17.—Ring Winding, Four Pole.

a ring of iron. The winding will now be recognized as the ring winding, which is the simplest of all the windings.

Consulting the developed diagram, it is easy to see that it might be extended to four, six, eight, or more poles by simply providing brushes to take off and feed the current at the proper intervals. The four-pole extension is shown in Fig. 17, as it has been used to some

extent in railway work. The problem of properly conveying current to the brushes is solved by connecting alternate brushes in parallel.

At this point it is well to call attention to an important general principle. Between adjacent bars of the commutator on this winding is connected an active coil, and this is universally true of all windings used in direct-current railway work, for on it depends the principle of commutation, which is most important in the study of sparkless running.

A multiplicity of brushes is to be avoided in railway motors. Two are of course necessary, and a number of devices exist to eliminate the need of more. The only device that could be applied to the winding just shown is that of cross connection. This is simply connecting opposite bars together, thus enabling one brush to feed at the two necessary places, and the other brush to take the current off at the proper places. A diagram of this method is shown in Fig. 18. This arrangement tends to divide the current in unequal amounts between the sections of the armature, for the cross connector has a sensible resistance, and sections fed by means of it receive less current than those fed directly. The advantage gained by the simplicity of two brushes is partially offset by the necessity of a larger commutator, for the brushes carry double current and, of course, need a proportionally longer bar.

Ring windings have been very popular in railway work, but are not modern practice. The active conductors are usually at a considerable distance from the axle, and this inherently long moment arm gives a strong torque. They are simple and easy to repair, and a single coil can be removed and replaced without in any way disturbing its mates. Another reason why the ring armature found favor was because the

potential difference between adjacent wires is very low and there is no crossing of wires of widely different potential on the ends.

The principal makes of motors that have used this winding were the Short motors manufactured

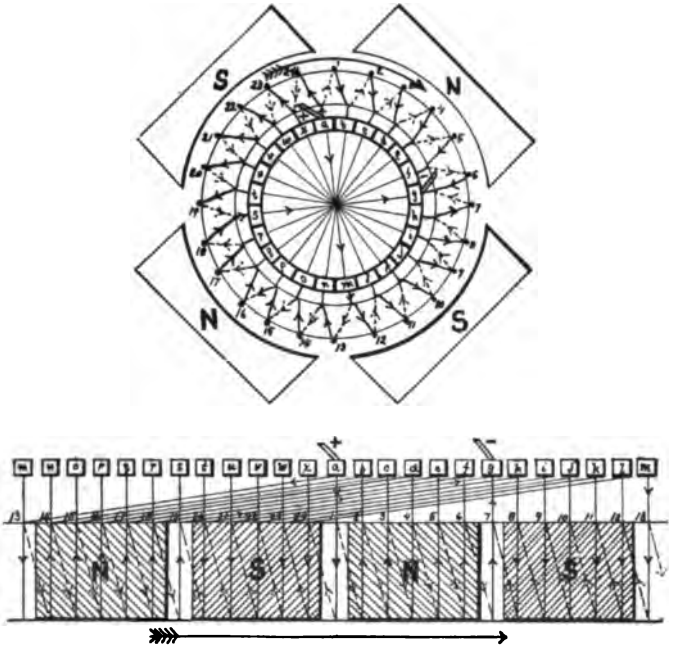

Fig. 18.—Ring Winding, Four Pole, Cross Connected.

by the Brush Electric Company. These motors were made in both two- and four-pole types. The Thomson-Houston Electric Company used the bipolar ring winding on the S. R. G. motors and also on the W. P. 30 and 50. The Edison General Electric Company used a four-pole ring-wound armature, and the early G. E. 800 motors of the General Electric Company were ring-wound. Abroad the ring winding is found in the Thury type of La Compagnie de

l'Industrie Electrique, the Oerlikon motors, and those of Ganz & Company at Buda-Pest.

The days of the ring winding in railway motor practice are past, for modern practice has rendered the drum armature more convenient to construct and repair. The necessity of a large hole in the center of a ring armature makes it bulky and of large diameter, which are now fatal objections in railway work. Moreover, if a railway armature has a large fly-wheel capacity serious loss of energy in starting and stopping will result.

Returning to the original problem, it will be noted in Fig. 15 that there are as many wires carrying current up in front of the north pole as there are carrying current down in front of the south pole. Now, if it were possible to connect these wires in a symmetrical manner we might utilize the up wires on the one side as a return for the down wires on the other side, and thus obviate the necessity of any return wires through the center of the armature. Such a winding would be entirely on the outside of the cylinder, and is called a drum winding, and there are many different methods by which it may be accomplished. One of the simplest is shown in Fig. 19, and tracing out the connections it will be found to fulfill the conditions of current distribution set down in Fig. 15. A more detailed description of this winding is appropriate because it is of assistance in understanding others which are similar.

All of the conductors are shown on the surface of the armature core, and it is supposed that there is just enough room for them all. This would constitute what is known as a surface-wound armature, such as was used on the early Sprague, Thomson-Houston, and Westinghouse motors.

Now, if we connect the rear of conductor No. 1 to a conductor carrying current in an appropriate direction, we must leave returns for the other conductors, so that the result will be symmetrical, for this is the foundation law of windings. Thus if we begin with No. 1 and connect it with No. 7, and continue connect-

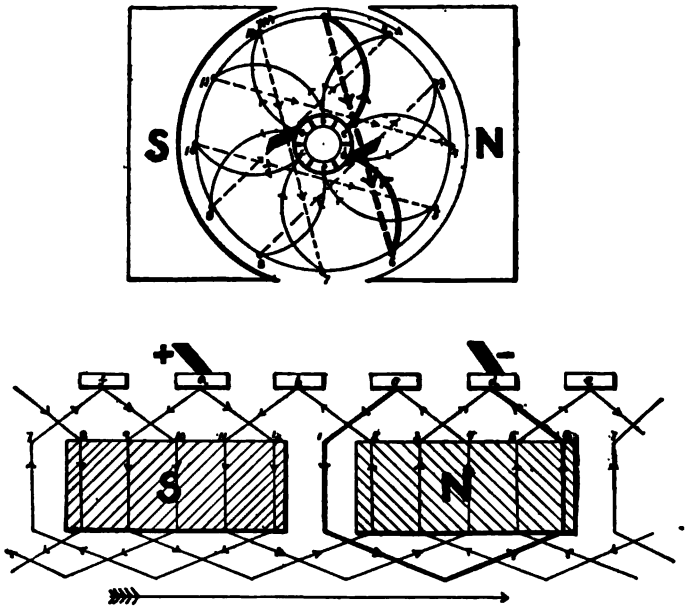

Fig. 19.—Simple Bipolar Drum Winding.

ing No. 2 with No. 8 and No. 3 to No. 9, etc., until we reach No. 6 to No. 12, we shall, it is true, have connected the ends together so that the current directions are fulfilled for that single position of the commutator, but as the armature is turned the required conditions are not fulfilled, because the winding would be unsymmetrical. If we connect No. 1 to No. 6, and then, leaving No. 2 as a return for a wire on the other side, connect No. 3 to No. 8, and so on, always an odd

number to an even one, we shall proceed around the armature in an entirely symmetrical manner and obtain proper connections at the commutator, so that, however the armature is turned, the current distribution under the pole pieces will always be the same. Another important point to notice in this winding is that each pair of bars is bridged by an active loop in the armature in the same way as in a ring winding, but with the important difference that for every two active conductors in the armature there is but one bar in the commutator, and thus there are half as many bars as conductors.

Owing to the fact that in a drum winding there is less dead wire than in a ring winding, and further because the construction of the core of a drum armature is much more simple than that of a ring armature, the former has become popular in railway work. An additional reason for this is that most railway motors are four-pole, and with a four-pole drum winding it is easy to arrange for two brushes without the device of cross-connecting the commutator. This will presently be shown.

The horizontal development of the drum winding just discussed is perfectly symmetrical, and therefore can be extended into two, four, six, eight, or any even number of poles in precisely the same way as can be done in the case of a ring winding, the number of brushes being increased in like measure, as shown in Fig. 20. This winding, which is known as a lap winding, has been extensively used in some form for multipolar generators, but because of the multiplicity of brushes necessary this has been abandoned in the case of railway motors for windings of the type shown in Fig. 21. This winding, it will be noted, has important differences from any heretofore shown. The

number of conductors in series is largely increased, being, in the case of a four-pole motor, twice the number involved in the system of winding shown in Fig. 20. It will also be found, by tracing, that between adjacent bars two active coils are connected instead of

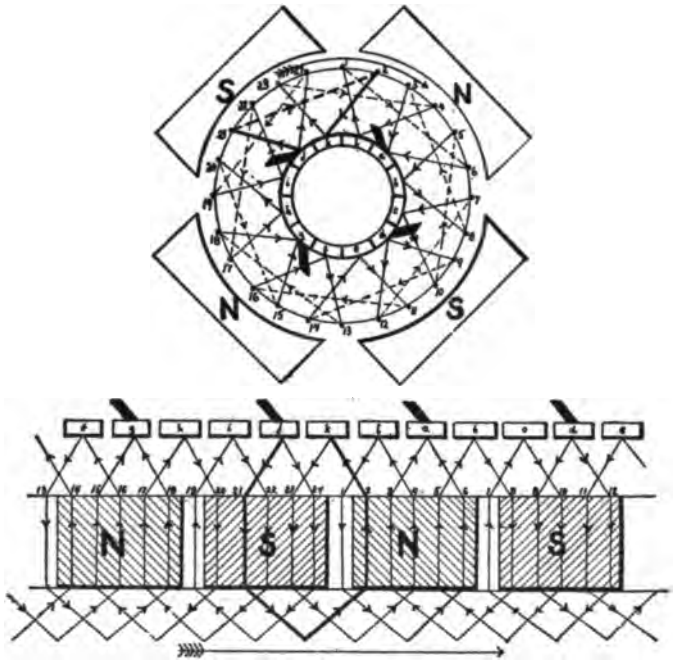

Fig. 20.—Four Pole, Parallel or Lap, Drum Winding.

one. The number of bars in the commutator is one-half the number of conductors in the armature, as with the ordinary drum winding, but the number of bars is always an odd number.

The reason for this is best appreciated by the student if he attempts to make such connection on an armature with an even number of commutator bars and a corresponding number of conductors. He will find that the first double coil proceeding around the

armature will bring him back to the segment from which he started, thus cutting out the rest of the winding.

This two-circuit, or series winding,—for so it is called,—if it had the same number of conductors,

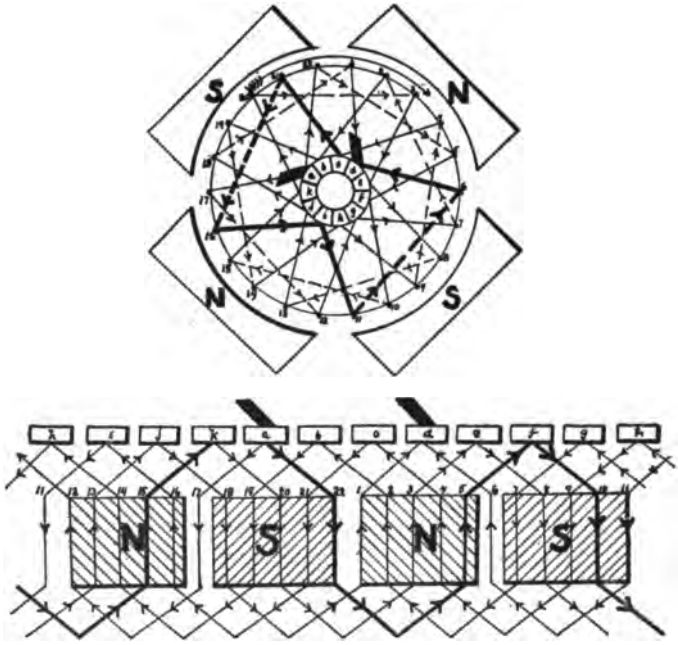

Fig. 21.—Four Pole, Series or Wave, Drum Winding.

would give half the speed of the armature having the ordinary lap or multiple winding; but as each conductor carries *one-half* of the total current of the machine, while each wire in the four-pole lap winding carries *one-fourth* the current, it will be seen that in order to retain the same capacity, the series winding must have half as many conductors of twice the size.

This winding was first used in railway work by the Westinghouse Company on the No. 3 motor.

Such a winding is sometimes called a wave winding, for the reason that the coils continue around the armature, rather than return and lap back over their mates. This is acomplished by merely altering the connections to the commutator bars. The mechanical positions of the coils are practically the same as in the lap winding.

The windings which have been illustrated are typical of those which are in use to-day, and the modifications which have been made are very slight indeed, although the casual view of a winding diagram, such as is used in practice, might present many points of difference and apparent complications. If these are considered singly they will resolve themselves into very simple matters. One of the most confusing of these modifications is a change in the lead of the commutator with regard to the armature. This has the effect of completely altering the general appearance of the connections, as shown in the winding diagrams. If we were to consider the leads connecting the commutator to the armature winding as completely elastic and flexible it would be possible to turn the commutator relatively to the armature without disturbing the electrical conditions, provided we made a corresponding adjustment of the brushes. By this device the non-sparking position of the brushes can be so shifted as to bring them into a convenient and accessible location. Thus with an armature whose poles are consequent, as in the G. E. 800 motor, the winding would be arranged as shown in Fig. 22, in order that the brushes should have the convenient upper position depicted. In an armature like the Westinghouse No. 3, or the Walker No. 5 A, or the later G. E. 52, in which the four poles pieces are arranged at 45 degrees with the horizontal, the direction of the commutator leads would have to be

shifted, as shown in Fig. 21, in order to secure the same desirable position for the brushes. Thus it is possible for two windings, which to the novice appear to be entirely different, to be electrically identical.

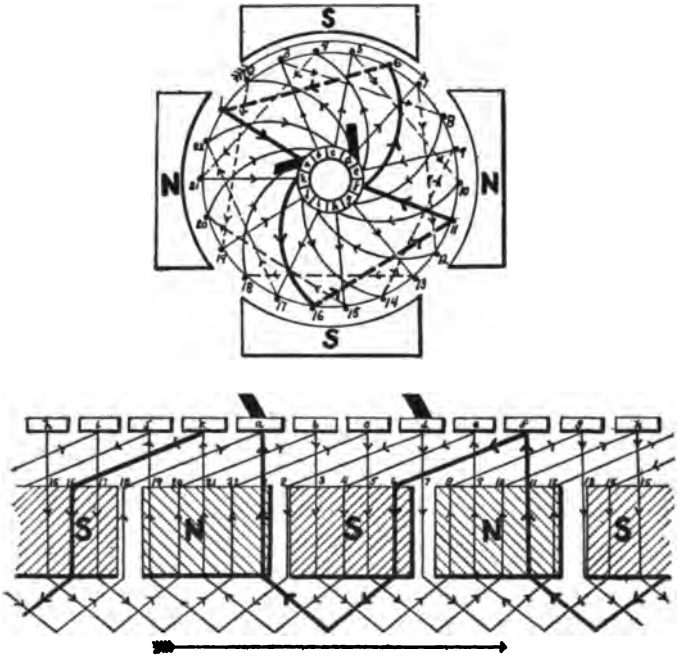

Fig. 22.—Four Pole, Series Drum Winding; Forty-five Degrees Lead.

This shifting of the commutator relatively to the armature is employed in many types of armature.

The windings illustrated have shown a single turn only to a coil, but this is true only with the more powerful motors. The smaller motors have a number of turns in series on every coil, and very often it happens that the same motor is wound differently, according to the service it has to perform. Thus, we have the W. P. 50, 9-turn, 12-turn, and 13-turn, and the G. E. 800, 3-turn and 4-turn, the last figures having refer-

ence to the number of turns in the individual coils on the armature. The armatures with few turns are speedier on level track, but are deficient in torque if wound with the same size of wire as those with more turns, as is usually the case. They should, however, give approximately the same torque if the same weight of copper and ratio between turns is used on armature and field. The amount of current used will of course increase as the speed increases.

To obtain lower or higher speed with correspondingly greater or less tractive effort, the Westinghouse Company began to use different gear ratios for its No. 38 motor. This has the advantage of always working the motor at the same H. P. capacity, and keeps all electrical parts the same.

In the diagrams that have been shown all of the active conductors have been assumed to be upon the surface of the armature, but this is never the case with railway motors in use to-day. It is customary to cut deep slots in the surface of the armature core and imbed the conductors therein. If we were to select a core of large enough diameter we could leave spaces between the wires large enough for teeth and imbed each of the conductors in a slot, and in this way we could adopt, without modification, any of the windings shown. Armatures of large diameter are not always desirable, and cutting slots in the core is expensive. Advantage has been taken of the fact that when there are many conductors, neighboring ones carrying currents in the same direction can be bunched together in a single slot. This reduces the number of slots and the labor of insulation. Thus, a single slot often carries many wires, and never less than two, on any modern railway motor.

If we apply the principle of bunching adjacent con-

ductors to the diagram shown in Fig. 21 we shall find that in no less than three cases conductors carrying currents in opposite directions will occupy the same slot, thus completely neutralizing each other's effect, as far as rotative effort is concerned. Fortunately

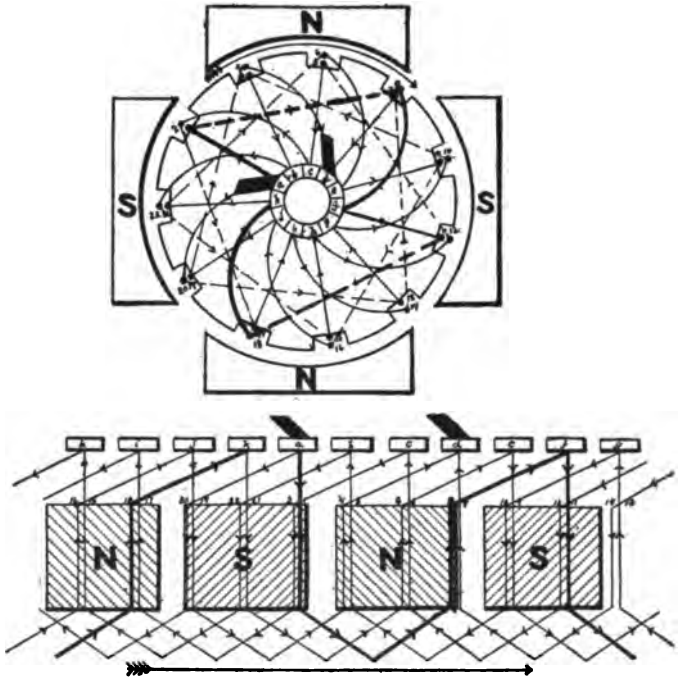

Fig. 23.—Four Pole, Series Winding, Bunched Slots.

these places come in the spaces between the pole pieces and are therefore of less importance than if they occurred elsewhere. However, this is a very real difficulty in winding design, and care is always taken not to have the neutral slots too numerous. The number of neutral slots is minimized by properly choosing the chord spanned by the coils. If this is either too short or too long there will be many neutral slots. Fig. 23

shows how the number of neutral slots of the modified Fig. 22 winding may be reduced to one, by simply increasing the chord of the coil one space.

A winding with a short chord is used by the West-

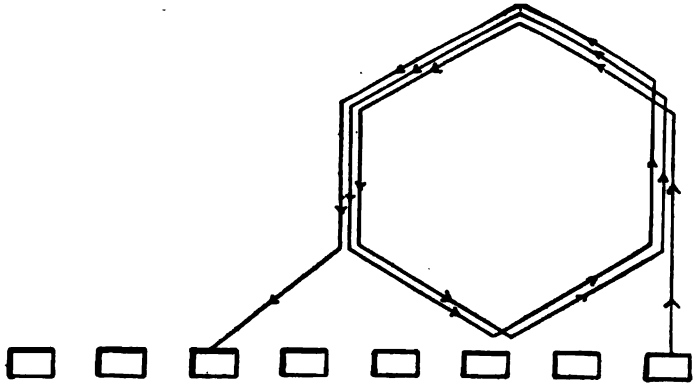

Fig. 24.—Method of Winding Several Loops per Bar.

inghouse Company exclusively, who claim that it reduces armature reaction both in demagnetizing of field and in reducing the self-induction in the com-

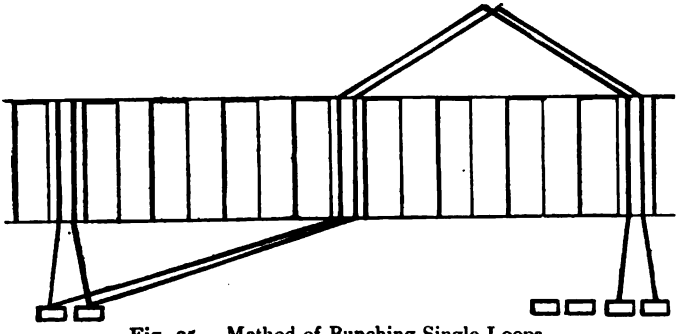

Fig. 25.—Method of Bunching Single Loops.

mutating coil. Also where there are several turns per coil, it decreases the end winding.

The simplest winding is, of course, the case of one turn per coil and one coil per slot, and before leaving

this branch of the subject, it is well to call attention to two modifications thereof. The first, given in Fig. 24, reduces the number of commutator bars and slots relatively to the conductors and is largely used on all of the smaller sizes of motor. The second device, shown in Fig. 25, reduces the number of slots only, but preserves the single turn per coil. It is used on the heavier windings.

The Westinghouse Company first used the bunched coils, in 1894, on the No. 12 motor, where the armature had 47 slots and 93 active coils and commutator bars.

It was carried still further in the No. 38 in 1895, where the armature had 45 slots and 135 active coils and commutator bars.

If the foregoing discussion of theoretical winding diagrams is well understood there will be no difficulty in comprehending the commercial windings that will be shown later.

CHAPTER III.

FIELD COIL CONSTRUCTION AND ARRANGEMENT.

UNTIL very recently railway motor field coils have been of the mummified or taped type. The principal reason for this was on account of the greater weight and bulk of coils employing spools of any form, and in railway motor design, space and weight are most jealously allotted to the various parts. The greater expense of supporting spools is a further consideration.

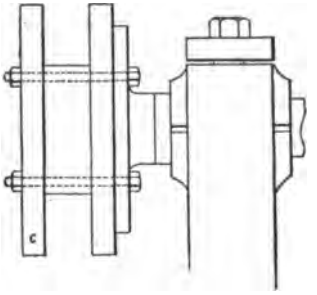

Fig. 26.—Form for Winding Field Coils.

In winding a mummified coil a wooden form of the type shown in Fig. 26 is generally used. It is intended to be screwed to the face plate of a lathe or winding machine, and the same bolts that hold it thereto also secure it together. The nut ends of the bolts are placed on the outer side for convenience in removing the flange C, to free the finished coil. To facilitate this latter operation the wooden core should be given a slight taper.

In order to retain its form when taken from the reel

such a coil must have stout tape wound into its turns at intervals to hold it together. To do this a strip of tape is wound in between the layers and lapped over the first few turns of the next layer, as shown in Fig. 27. As the wire on most railway motor field coils is quite heavy, considerable of this taping must be done on every layer. Two sets of tapes must be carried up,

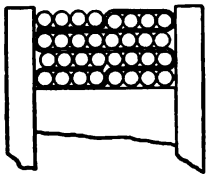

Fig. 27.—Securing Wire by Tape.

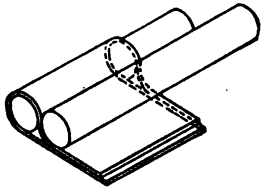

Fig. 28.—Repairing Insulation.

the one binding the layers that the other omits. As the wire is wound it should be carefully inspected for breaks in the insulation, and where these are found they should be carefully wrapped with cotton yarn, or, better still, covered with cloth or varnished paper, as shown in Fig. 28. The paper is looped about the wire over the bare spot and the adjacent turns hold it in place. To secure the first and last wires so that they will not unwind they should be tied with strong cord,

Fig. 29.—Securing Last Turn.

as shown in Fig. 29, several cords being caught under the next to last turn and the ends firmly knotted together when the winding is complete.

It is common practice to solder flexible leads on to the ends of a field coil and depend on them for perma-

nency. Too often such leads are used as convenient handles in moving the coils, and are broken off short or the winding otherwise damaged. This difficulty is obviated by the use of a terminal of the type shown in Fig. 30. It is of cast brass, and its application will

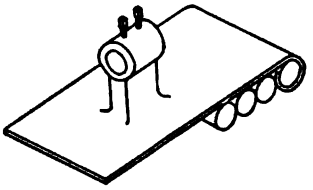

Fig. 30.—Terminal Plate.

be readily understood. The end of the winding is securely soldered into the socket provided for it and the protruding terminal is drilled and tapped to secure a wire, as shown. The heavy taping which the coil ultimately receives firmly secures this plate from moving. The waterproof qualities of the winding will be improved by using wire that has been run through hot paraffin before winding.

The completed coil should be served with two layers of strong cotton tape. Adhesive tape should not be used, as it is not strong enough to be drawn tightly and always contains a certain amount of moisture. After the first layer of tape is tightly wound on, the coil should be painted with P. & B., and while it is still sticky another layer of tape should be put on, the winder being careful to lap the joints of the first layer. After two more coats of P. & B. have been applied the coil is ready for baking. If no convenient means are at hand for doing this the coils may be connected in series and enough current passed through them to heat them. If the pressure at hand is 500 volts, as is usually the case, the more coils that are connected in series the less

outside resistance will be necessary. The outside resistance may be a few old rheostats. A good method is to provide an asbestos-lined box, and place the coils and car rheostats therein. In this way the heating effect of all of the current will be utilized. The heat which the coils receive from the current they carry is the best which can be applied, and will bake the coil more quickly and thoroughly than in any other way.

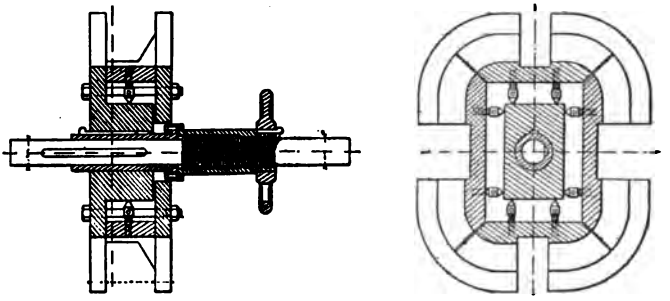

Fig. 31.—Form for Winding Odd Sections.

In applying current to field coils for this purpose it should be remembered that railway motor field coils are not, as a rule, designed to carry their full load current continuously, for advantage is taken of the fact that in practice the current is of an intermittent nature. They are, therefore, made smaller and lighter than would be permissible if the full load was steadily maintained. On motors for interurban railways the field coils are made heavier for obvious reasons.

In motor field coils the section of which is not rectangular, such as those of the G. E. 800, the Thury, and Oerlikon types, and, in short, all of those in which the field coil surrounds the armature in part as well as the pole piece, special tools and forms are necessary. The details of such a form are shown in Fig. 31. With

bipolar motors such hollow-constructed coils as this were quite necessary to avoid leakage from the pole tips to the sides of the casing, but with the four pole types, the points of widely different magnetic potentials are not so closely adjacent.

The standard type of coil for the Westinghouse motors is shown in Fig. 32. It is wound in a curved

Fig. 32.—Bent Field Coils of Westinghouse Motor.

form and surrounds the armature, giving a most compact construction, as no room in the motor is wasted.

When the windings of the field coils are very heavy their construction becomes quite a problem. A frequent expedient has been to use several wires wound and connected as a single conductor. It is almost as easy to wind two or even three wires side by side as to wind a single strand, and in this way flexibility in heavy conductors is often secured.

The use of copper ribbon has of late become very popular, partly because a very compact coil can be made from it and partly because it is easy to wind and can be thoroughly insulated with asbestos and other fireproof materials and will therefore withstand ex-

ceedingly high working temperatures. Fig. 33 shows the easiest and most common method of winding such a spool. The ribbon is wound on in layers one turn per layer. The inside end is brought out by bending, as shown in the figure. It is easy to see that such a construction is very well adapted to insulation with

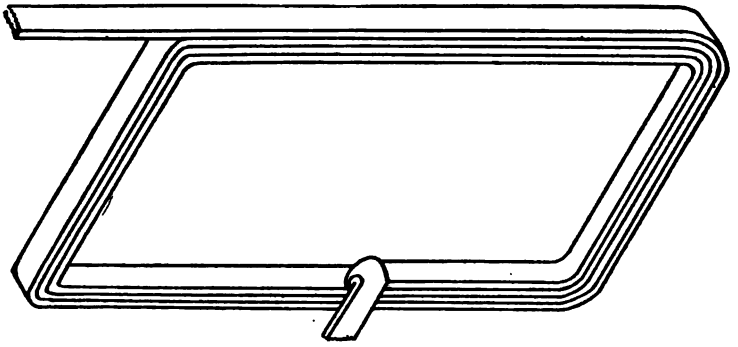

Fig. 33.—Ribbon Wound Coil.

strips of asbestos and mica, for by the very shape of the conductors such insulation is securely held in place.

Another and very ingenious method of constructing ribbon-wound coils is shown in Fig. 34. In this method no attempt is made to bring out the inside end. There are two coils wound in opposite directions and so constructed that when placed side by side the inside ends can be easily brazed together. The free outer ends form the terminals. The two coils are thoroughly insulated with asbestos and securely taped together. This practice was first introduced on the No. 15 and 20 L motors built by the Walker Company, and was also the method used by the Westinghouse Company in wire winding on their No. 3 motor.

The early field coils were wound on removable spools with fiber sleeves and fiber heads. The rapid deterioration of the fiber very quickly caused this con-

struction to be abandoned in favor of brass spools and frequently sheet-iron spools with brass heads. These were insulated with fiber and later with fuller-board and mica, and became standard practice, appearing on the S. R. G. Edison motors and even on the early G. E. 800 motors of the General Electric Company. The

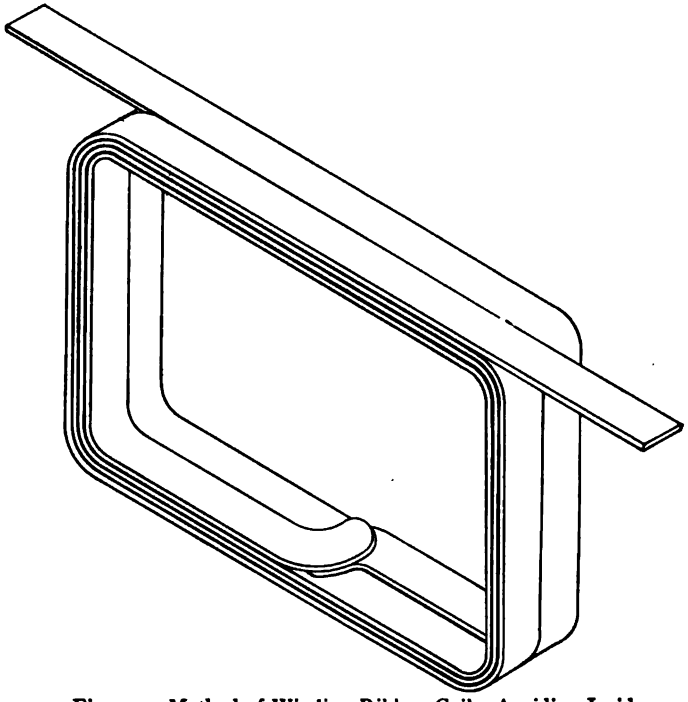

Fig. 34.—Method of Winding Ribbon Coils, Avoiding Inside Connections.

first motors of the Steel Motor Company also used spools, and abroad even to-day removable field spools are used exclusively. In some cases the wire was wound directly on the pole piece where that member was removable, and it was fitted with brass collars on either end to confine and support the wire.

The movable field spool was a great convenience, as it protected the coil and was easily secured in place by the simple device of casting lugs on it at appropriate places.

With the advent of the four-pole inclosed motor, which was due to the Westinghouse Company, the field spool was abandoned for the mummified coil described in the first of this chapter. It then became imperative that such a coil be held firmly and the possibility of its chafing under vibration be entirely eliminated.

The method used almost universally is to secure the coil by clamping it with a casting held by one or more

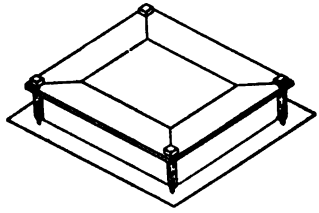

Fig. 35.—Westinghouse Method of Securing Field Coils.

screws. The Westinghouse method shown in Fig. 35 is an example of this. The clamping casting is a rectangular frame, and four bolts secure it to the case, passing through the latter and being secured by nuts on the other side. In this case the clamp, beside holding the field in place, affords a substantial protection for the coil, in fact as good protection as if it were wound on a spool.

The field coils of the smaller sizes of the Walker motor are held in pairs by castings shaped as shown in Fig. 36. While this method does not protect the coil as fully as the one just recited, it has the advantage that only four bolts are necessary to hold in all four field coils, and hence they are very easily re-

moved. These bolts have no nuts, but are threaded into the case.

In 1895 the Westinghouse Company brought out the No. 38 motor, which was designed on similar lines to their No. 12 A, except that the field was made of cast steel with laminated pole pieces which were cast in. This was so great an improvement in increasing the efficiency that the use of laminated poles has become general among all manufacturers; but instead of

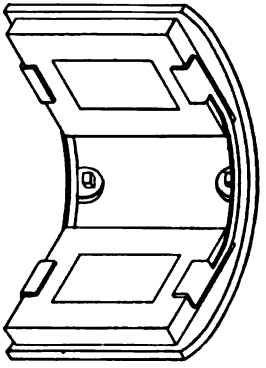

Fig. 36.—Walker Method of Securing Field Coils.

casting them into the yoke, they are bolted in and are shaped to form a pole shoe which assists to confine the field coil. In the first motors of this class the pole shoe was depended upon entirely for this purpose, but in later types brass clips were placed at the corners, as shown in Fig. 37. These in time extended into broad plates, and now in the latest practice of the General Electric Company, have returned to complete metal spools once more, as shown in Fig. 38.

Railway motor field coils are now always connected in series, even the largest sizes. The principal reason for this is the certainty of obtaining equal magnetization for all the pole pieces. It is easily possible to

wind each pole with an exactly equal number of turns, and if this is done they are bound to give equal mag-

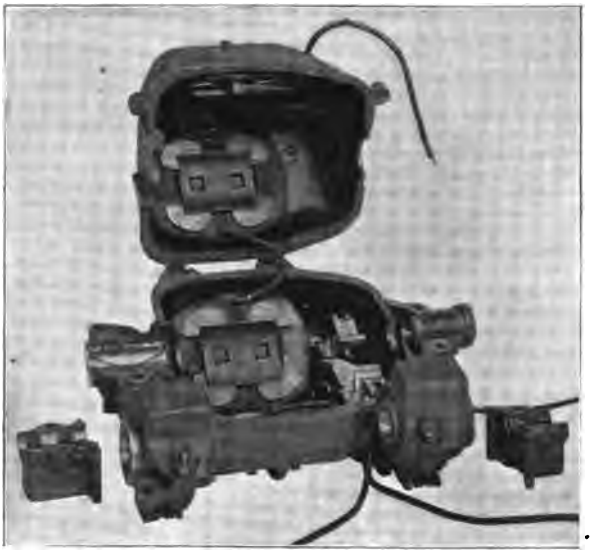

Fig. 37.—Securing Field Coils by Pole Pieces.

netic effort, no matter if their resistances are unequal. The terminals as they are to be directly connected to the car wiring consist simply of flexible leads passing

Fig. 38.—Spool Wound Field Coils of G. E. 55 Motor.

through soft rubber bushings in the casing. In the earlier motors it was common to provide a block or box in which were mounted appropriate binding posts, but it was quickly found that such devices simply

formed a lodgment for mud and dirt and a general location for short circuits and poor contacts. They were expensive and a decided disadvantage, and were accordingly abandoned.

Owing to the very high temperature at which railway motors are worked, some companies wind their field coils with asbestos-covered wire. The Westinghouse Company advocates a lower temperature on field coils and secures it by using large wire and decreasing the turns, thereby securing also a more efficient motor. This advantage is secured at an increase of weight for a given horsepower, for, other things being equal, the higher the working temperature the greater the output.

CHAPTER IV.

ARMATURE CONSTRUCTION.

In Chapter II., on armature windings, it was shown that the cylindrical surface of an armature is covered with conductors parallel to the shaft, and that these conductors are so connected that when currents are sent into the armature at certain points on the commutator they will flow in these conductors in such a direction as to produce rotation of the armature core to which they are fastened. While it is a simple matter to draw lines suitably representing the various wires, it is by no means as easy to run wires which actually convey current from one conductor to another. There are so many of these conductors that they interfere with each other, and before the systematic arrangement of the present day had been perfected, the ends of every drum armature presented a most unsightly wad of wire, which was composed of the various connectors running from section to section and heaped upon each other in great confusion.

There are two types of railway armatures, the drum and the ring. The ring armature is the simplest as regards mechanical winding, and will be first described. The obvious way of winding a ring armature is by wrapping the wire around the torus of the ring, and if it be neatly done, a smooth symmetrical winding will result. There are only two ring armatures which are used at present in American electric railway motor work; they are those of the W. P. 50 and 30 of the Thomson-Houston Electric Company, and the

Short motors made by the Short Electric Railway Company, formerly of Cleveland, Ohio. Both of these armatures are wound with flat wire in order to build up a more solid bobbin. The Short motor was wound in bobbins of several layers, a lead being brought out from the middle of the bobbin in order to subdivide it and diminish the number of turns per commutator bar. The wire was equivalent to a circular section of about .09 inch in diameter; and a very substantial winding was formed, which was strengthened by layers of cloth, wound in as the work progressed. These prevented the outside wires from falling down as the bobbin was built. In Fig. 39 is shown the method by

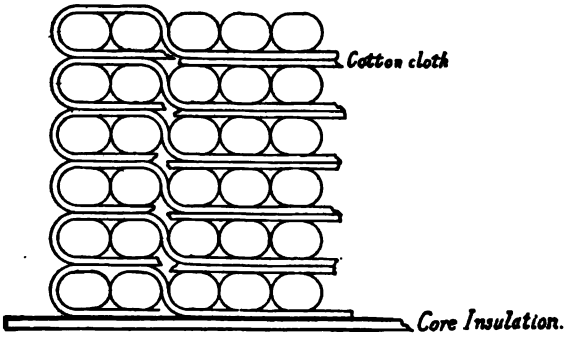

Fig. 39.—Insulation of Short Ring Winding.

which this is accomplished. The bobbin is wound in a box or trough formed of fuller-board and mica insulation. The active wire of this armature is carried on its sides, and between each of the coils are small teeth. Indeed, this was one of the first toothed armatures ever constructed for railway work.

Both the 15 h. p. and 20 h. p. W. P. motor windings are alike, so far as mechanical method is concerned, and the description of the W. P. 50 winding will suffice. As before stated, a flat conductor is used.

It could be more appropriately termed a ribbon, for it is .34 inch broad by .04 inch thick, and is insulated with cotton winding. The cylindrical surface of this armature is slotted to receive the active portion of the wire, and the latter is wound in these slots, one turn per layer, until the requisite number of turns have been filled in. It was customary to wind these armatures in three different ways, according to the work that they had to do, with 9 turns, 12 turns, or 13 turns per bobbin, those having the greatest number of turns possessing the most torque, while those of fewer turns have higher speed. The character of the output on railway armatures, even at the present day, is often varied in this way. This variation of torque only obtains when the size of wire is not changed but the turns simply are varied.

The slots of the W. P. armature are insulated by mica and fuller-board, and the other parts of the core are also protected with an insulating covering. The wire is secured by driving in a piece of wood of semi-circular section, which is held in place by the T-shaped projections of the teeth, as shown in Fig. 40, thus

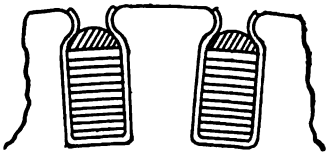

Fig. 40.—W. P. 50 Motor Winding.

avoiding the use of band wires. Band wires on a ring armature are not absolutely necessary, for the reason that the method of winding is such that it inherently secures the wire very strongly in place.

Abroad the ring armature has found favor among many makers. Prominent among such motors are

those of Thury and of the Oerlikon works. The armatures of these motors are very like those of the Thomson-Houston W. P. motor, being ring-wound with overhanging teeth.

We now pass to drum armatures, the construction of which is more complex. The first drum armatures were smooth-bodied affairs, and were divided into sections by fiber pegs driven into saw cuts in the end disks. Having suitably insulated the armature core, the usual method of winding was to secure the end of the wire, then wind on a coil by hand, and having completed one, to start another, suitably covering with insulation the points where the wires crossed on the ends of the armature. The first one or two coils went on smoothly enough, but as the winding progressed, the path of the wires over the end of the armature became more and more uneven, till the final coils were some 10 or 15 per cent. longer than the first ones. This work was covered with a canvas head to keep out the dust, but such a construction did not fail to be a fruitful source of faults which frequently resulted in burnouts. Moreover, if an accident overtook one of the coils, at least all of the coils which had been wound over it would have to be removed, even though they were in perfect condition, in order to get at the faulty one.

Various methods of winding the coils in groups were used, so as to equalize in a measure their length and resistance, and thereby avoid the commutator troubles to which such electric unbalancing gave rise. As such surface-wound armatures as this are now universally discarded, it is not necessary to describe their construction at length, but what has been said is of interest, because it points out how the railway armature has been improved.

The slotted drum armature introduced by the Westinghouse Company in its No. 3 motor effectually demonstrated the superiority of this type for railway work. A core covered with slots was very much easier to wind than a smooth-body armature, for the wire was very much less likely to become displaced. The machine-wound armature coils placed on this motor were for the first time used for railway motors, and were a distinct advance in armature construction at that time.

Of course ring armatures inevitably demanded hand winding with a shuttle. The system of formed coils had many attractions. Cheap labor could be employed in winding them, for they were not difficult to construct, and it is always easy to perfect even an uninformed laborer in the construction of a simple member, and if he has to make hundreds of these he will soon become more expert than his instructor. Besides these advantages, the formed coils could be insulated separately, and hence much more thoroughly. The winder could slip on the coils and shape up the heads in a fraction of the time that was necessary when the old method of winding the wire by hand was employed.

The first of these coils were made as shown in Fig. 41, a simple rectangular affair. The back connectors are given a half turn so as to enable them to pack in place over the ends in a more substantial manner. Fig. 42, which illustrates such a winding, will show how this twist assists in the assembling of the coils. By winding the armature in groups the advantage was secured that in case of accident to any coil, all of the coils that had been subsequently put on need not necessarily be removed. In order to accommodate such a construction, the coils were often made in sets of vari-

ous lengths. Those, for instance, of the Westinghouse No. 12 motor had twenty-three short coils and twenty-four long ones.

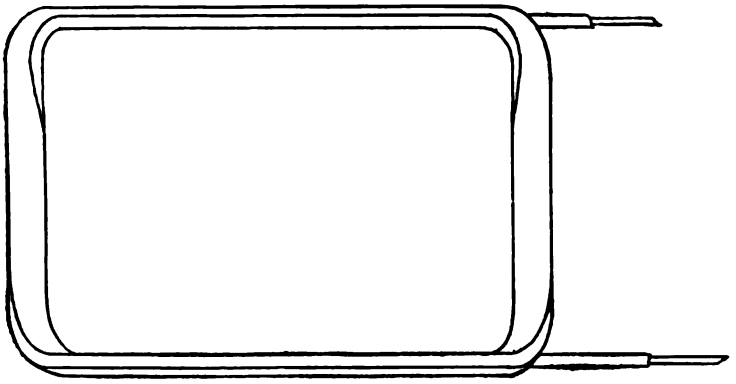

Fig. 41.—Early Formed Coil.

Even previous to the use of the formed coils already described, Rudolf Eickemeyer had invented and pat-

Fig. 42.—Method of Application of Early Formed Coils.

ented a formed coil-winding which was superior. The patents covering this winding became the property of

the General Electric Company, which incorporated the principles in its well-known G. E. 800 motor.

If we look at the end of a drum armature and notice the connectors passing from slot to slot, it will be seen that they can be divided into two layers, one half of the connector serving to form part of the lower layer next to the core, and the other half the upper layer. Dia-

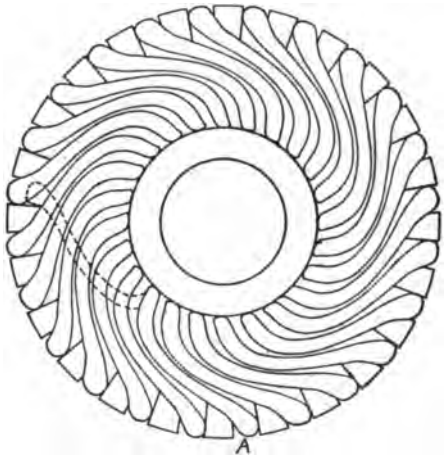

Fig. 43.—Eickemeyer Winding.

gram 43 will make this plain. The outer layer is shown in full lines and a connector in the layer next the core in dotted lines. It will at once be seen that the wires comprising a layer in such a formed head do not cross each other anywhere, and the wires of the upper layer crossing those of the lower layer can be separated therefrom by a single thin circular sheet of insulation. Moreover, such an armature head is very compact, and in a railway motor this is an enormous advantage, as the available dimensions are often limited, and a motor that is too long in the direction of the car axle may interfere seriously with the work-

ing of the brake rods or with the use of an improved suspension.

That the compactness shown by the diagram is realized in practice is demonstrated by Fig. 44, which shows a G. E. 800 armature in process of winding. The inner and outer layer may be distinctly seen, and

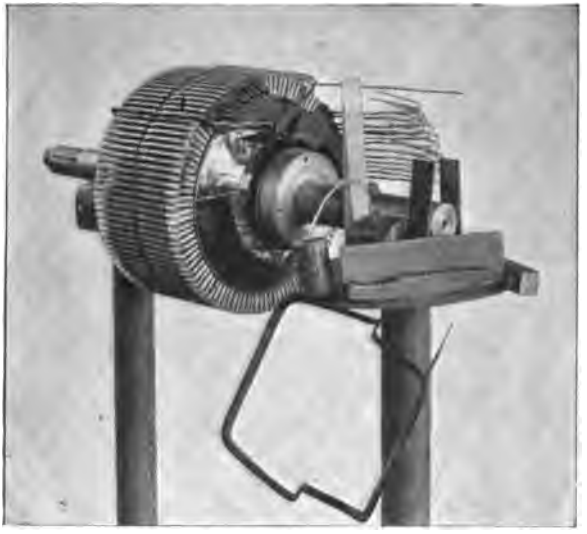

Fig. 44.—G. E. 800 Winding. Eickemeyer Plan.

also the way in which the armature coils fit together. The principle of this winding may be made still further apparent by noting the shape of an isolated coil in which it will be seen that the wire passes outward from the slot and down toward the axle in an involute curve, forming a part of the outer layer, when it bends sharply inward parallel to the axle, and turning sharply again, passes upward to its proper slot in an involute curve, which is the inverse of the first one, thus forming part of the inner layer of end connections. Like

the W. P. 50, the G. E. 800 coils are wound with three, four, or six turns, according to the service.

A popular idea with these formed coil armatures is that the winding is a matter of simply slipping the coils on one after another till the armature is completely wound. This, however, is not as simple a matter as it would at first seem, and it will be best appreciated by considering the difficulty of taking apart a completed armature.

Consider diagram Fig. 45. We wish to remove the coil marked X. One side of it is in the upper part

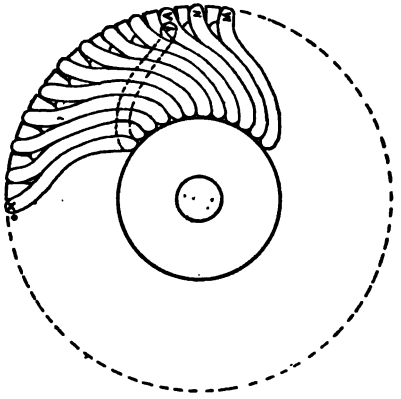

Fig. 45 —Showing how Eickemeyer Coil Is Bound in by Its Mates.

of a slot and can be easily lifted out, but the other part of the coil is in the lower part of the slot, and the conductor above it must be lifted out first. Nor is this all; every other upper conductor in the span between the two slots pertaining to the same coil must be lifted to liberate the damaged coil. This will be readily seen by consulting Fig. 46. In a four-pole series-wound machine this means lifting one-half of all of the upper conductors in the armature, because the commutator leads are also confined by coils beyond those in the

slots spanned by the coil to be removed. The lifting action is a progressive one, increasing in arithmetical ratio. Thus, if it is desired to lift coil No. 1, coil No. 2 must be lifted twice as much, and coil No. 3 three times as much, and so on. Besides this lifting

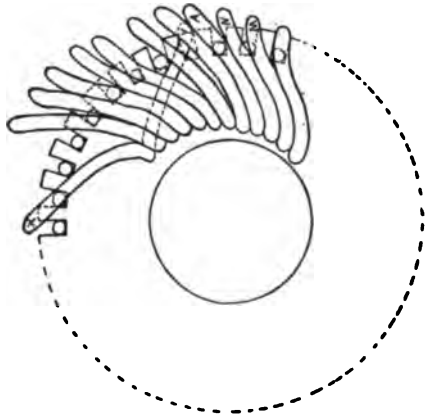

Fig. 46.—Removal of Eickemeyer Coil.

of the obstructing coils they must also be disconnected from the commutator.

The result of this is to deny to the formed coil the advantage which is often claimed for it, that of particularly easy repair. If an armature be run for a considerable period of time, and one of the coils fails, it is next to useless to try to replace that coil alone, for the lifting of the other coils which this operation entails is certain to crack and destroy their insulation so much that they are not fit for further service. The armature must be stripped and rewound.

The construction of an Eickemeyer armature coil is not an easy task to the uninitiated. It always requires a special winding form. One of the simplest of these is shown in Fig. 47, which consists of a flat

piece of board fitted with suitably spaced pegs around which the coil is wound. As the winding proceeds the pins at the angles of the inner turns require to be stepped from hole to hole to make room for the wires. The coil being taken from the form in this shape is

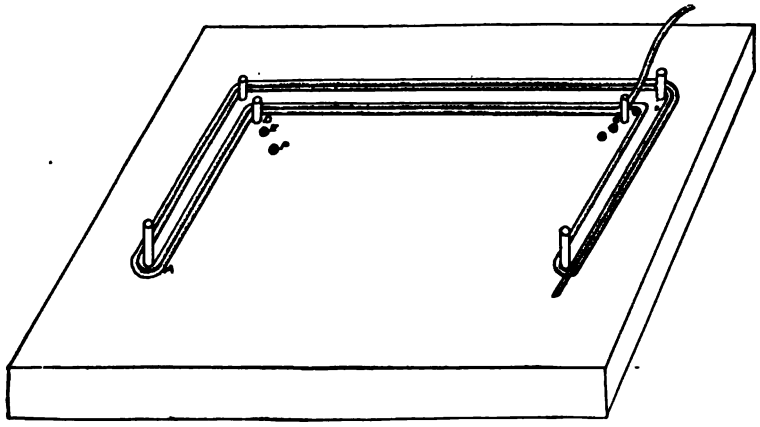

Fig. 47.—Form for Winding Eickemeyer Coil.

secured together with pieces of twine and is then opened up to the proper shape by hand. Fig. 48 shows another device utilizing this same principle, but more conveniently. This form has been used in France in the construction of the Eickemeyer windings.

It is also possible to make a brass or wooden form on which the coil may be wound and which will produce the coil in its final shape without subsequent bending. These forms require some device by which they may be separated or collapsed in order to permit of the removal of the coil and they require fillers of peculiarly shaped pieces of metal, which are fitted into the form and changed from turn to turn in order to compel the wire to occupy its proper position. The results from such forms as these are much better than

those in which additional bending by hand is necessary. In taping an Eickemeyer coil it is very necessary that it be laid on tightly and neatly, for each coil, as will easily be seen from the foregoing illustrations, occupies a certain space on the armature, and lumpy, irregular taping is very likely to cause the winder

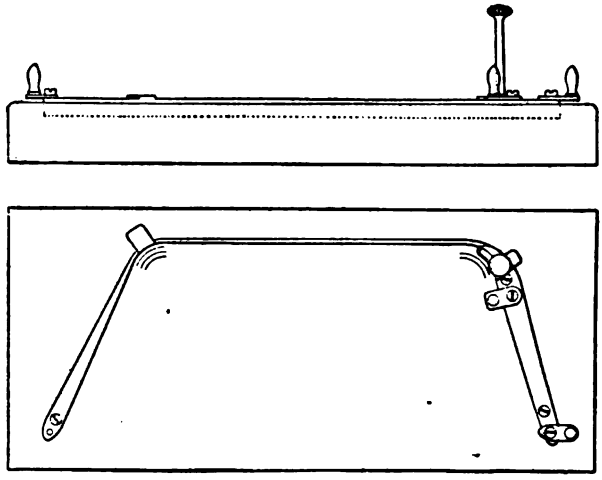

Fig. 48.—Form for Winding Eickemeyer Coil.

trouble, particularly at the sharp bend occurring at the change of plane at the end connectors. At this point it is very easy to do careless taping. The General Electric Company developed the taping and forming of these coils to a very high degree, and claims great uniformity for its product in this department. The taping is done by machinery. The best tape to use on formed coils, as a general thing, is a plain cotton tape, which is afterward served with shellac or other suitable varnish. Cotton tape can be wound on much more strongly than adhesive tape. Ordinary friction tape, which is sticky on both sides, should never be used, because a sticky coil is very difficult to adjust when

placed among its fellows. There is a tape of the adhesive variety which is sticky on only one side, and this has been used to considerable advantage in insulated armature coils, but in general it may be said that all adhesive tape contains more or less moisture which is detrimental to the installation, and that this kind of tape is lacking in mechanical strength.

American railway motors now use drum-wound armatures exclusively, and numerous methods have

Fig. 49.—Straight-Out Winding.

been tried to secure a symmetrical system of winding them. A recent development, and one which is now largely used, is the straight-out winding. This is so called for the reason that the ends of the coil project straight out from the ends of the armature in a plane parallel to the shaft, as shown in Fig. 49. This has the advantage, first, that the coils are simply polygonal figures, having no intricate curves requiring special forming devices, and, second, because the shape of the coil, being practically all on one plane, is such that it is easier to remove it.

The first straight-out windings were constructed

with the end of the coil protruding in a more or less unprotected manner. The coils formed a sort of cylindrical wall or ring protruding from the end of the armature, and were usually protected by tape wound on the coils individually and on the assembled ring as a whole. The first impression would be that such an armature as this would be altogether too long for any purpose, and this would particularly be the case for a railway motor. This, however, is an objection that does not materialize in practice. The straight-out winding has the advantage that it can overhang the

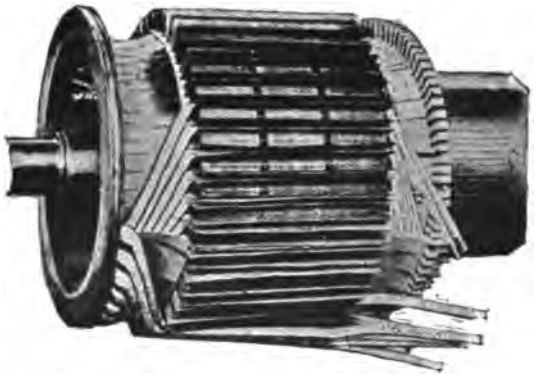

Fig. 50.—Straight-Out Winding With Shield. Walker.

bearing, which was impossible in case of the Eickemeyer winding, and for this reason the dimensions of the motor are only very slightly increased in a longitudinal direction. The straight-out coil has less inactive wire than the Eickemeyer coil, thus increasing the volts per foot of wire on the armature and reducing the resistance of the latter.

The unprotected straight-out winding overhanging the bearing is likely to become saturated with oil and dirt thrown out from the central part of the armature and bearing by centrifugal force, and being liable also

to mechanical abrasion, it was necessary to protect it in some way. To do this an improved method was devised which is now being universally adopted. This is to provide a metal support for this ring, which is usually a part of the end disk which holds the laminæ of the armature together. Such a construction is shown in Fig. 50, which illustrates the practice of the late Walker Company. It may be mentioned that this figure illustrates a simple dynamo armature wound on this plan, but it is selected because it shows the principle of this method of winding to excellent advantage. Fig. 51 shows

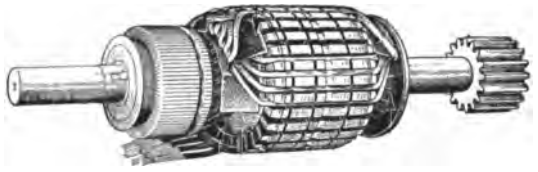

Fig. 51.—Straight-Out Winding With Shield. General Electric.

how the General Electric Company has utilized the principle on its G. E. 57 motors. Fig. 52 is of assistance in understanding the application of these end rings. It depicts a sectional view of the Walker 200 horsepower elevated motor, the section being taken through the armature, and it shows how the end connectors and their supporting shell can overhang the bearing. An extreme case of economy of space by this device is that of the G. E. 55 motor, a late production of the General Electric Company. Another, shown in Fig. 53, shows how the Westinghouse Company allows the bearing to project into the armature

overhang for the sake of space economy in their elevated railway motor.

The straight-out coil is made with a number of turns in the small sizes of motor and with a single turn in the larger sizes. Its construction is much simpler than that of the Eickemeyer coil. A simple wire-wound

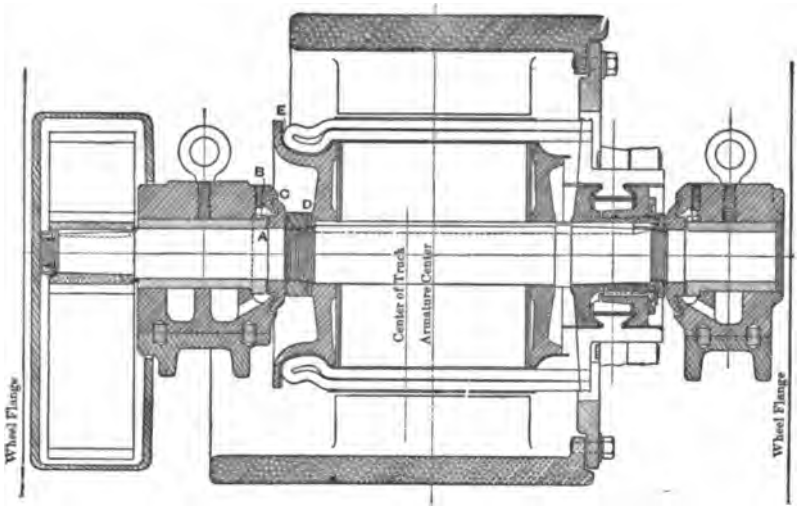

Fig. 52.—Section of Walker No. 25 L.

coil may be made by winding it upon two pegs in a board, as shown in Fig. 54, and removing it therefrom. It can then be secured together with strings and opened up into shape. This is the most common method employed. Like the Eickemeyer coil it is possible to make a form which will produce the coil complete without subsequent bending, and the results are somewhat better as regards uniformity, which is a great desideratum in this class of armatures. Fig. 55 shows a wire-wound straight-out coil stretched into shape. The same precautions as were employed in the Eickemeyer coil as regards taping and bending are to

be observed. It is to be remarked, however, that as the change of plane in the end connectors is about

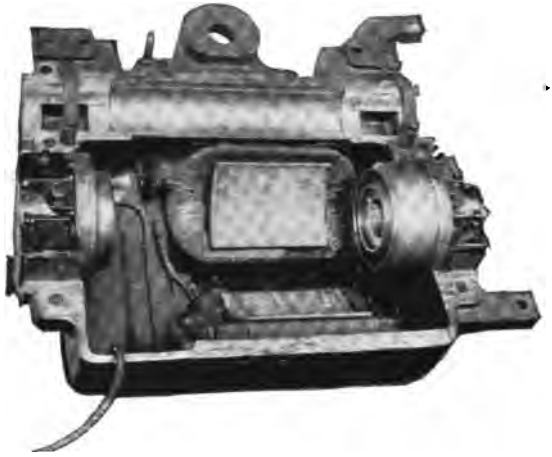

Fig. 53.—Westinghouse Elevated 150-H. P. Motor Case.

equally distant in radial direction from the shaft with the rest of the winding, there is ample room for a considerable lump, and therefore work that would not pass

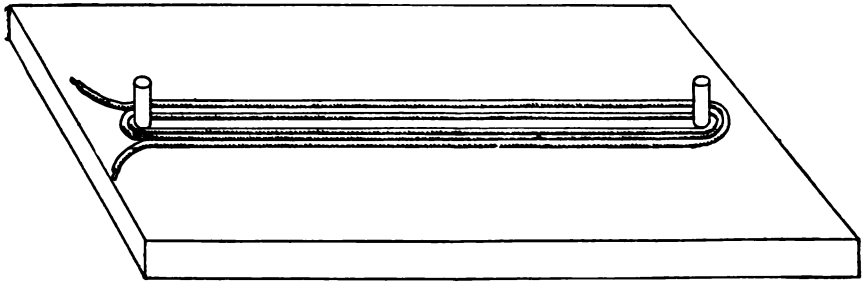

Fig. 54.—Form for Winding Straight-Out Coil.

at all in Eickemeyer construction, will find plenty of room in an armature wound on the straight-out plan.

The Westinghouse Company has a new winding which is used on all of the new motors, No. 56, No. 60, and No. 69, which has some advantages over the

straight-out coils. It takes a shorter space than the straight-out winding and is said to be as rigid as if it had the iron support under it. An example of this is the No. 56 armature shown in Fig. 56, where

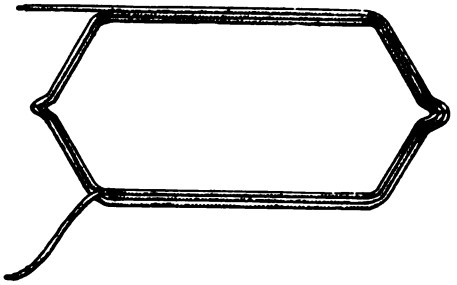

Fig. 55.—Straight-Out Coil Complete.

the winding projects 2¼ inches beyond the armature end plate and drops the same distance below the surface of the armature. This makes the over-all length considerably less than other motors of similar capacity.

Fig. 56.—Combination Straight-Out and Eickemeyer Winding. Westinghouse.

These coils are all wound to their final shape in one operation on a lathe.

The use of a formed coil necessitates a straight slot without overhanging projections, and this has introduced some difficulties in motor construction. Straight teeth are likely to heat pole pieces of the

motor by causing excessive eddy-currents. This has, however, been done away with, as will be seen in subsequent chapters, by the use of laminated poles. To protect the coils in their slots they are usually made

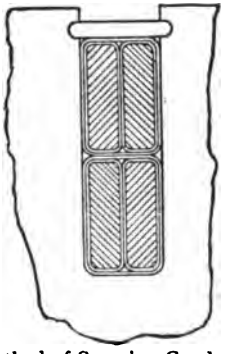

Fig. 57.—Method of Securing Conductors in Slot.

deep to allow room for a wood filler from 3-32 to 1-8 of an inch in thickness. This protects the insulation from being punctured when the armature is rolled across the floor. In some cases the filler has been used

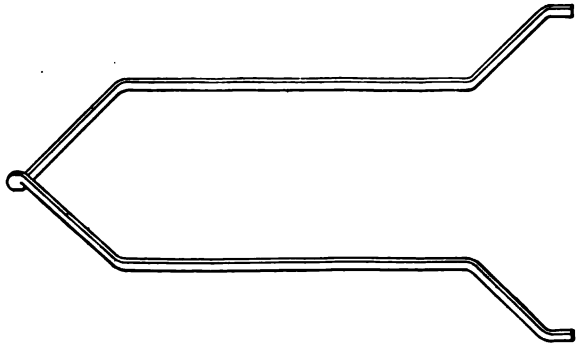

Fig. 58.—Ribbon-Wound Straight-Out Coil.

as a means of confining the coil, by the device of providing notches in the side of the slot and driving the filler into them. The section of such a slot is shown

in Fig. 57. This method is open to the objection that if the filler should ever be called upon to resist the strains of centrifugal force, it is likely to split, for its grain is in the wrong direction to resist such strains, and, moreover, the construction is expensive. It has, however, been used in recent practice. Filling sticks are also used to occupy vacant space when motors are wound with fewer turns per coil for the purpose of varying their speed.

If the machine is of large capacity a simple loop between the commutator bars constitutes a coil. These loop conductors are frequently made of flat ribbon, which is very conveniently manipulated, the only difficult part being the abrupt bend at the sharp angle of the coil. Such a coil is shown in Fig. 58. These coils are usually made with a machine-formed

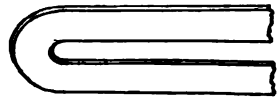

Fig. 59.—Machine-formed Bend.

bend, as shown in Fig. 59, the two lengths of ribbon extending parallel to each other. Thus bent the coil is formed to its final shape by bending it about a wooden block, or in a repair job it may be shaped with a pair of pliers. A substitute for the machine bend

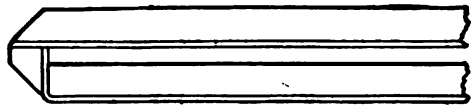

Fig. 60.—Substitute for Machine Bend.

can be made, as shown in Fig. 60, which consists simply in folding the ribbon on itself. This has the disadvantage of producing two more sharp bends in the

ribbon and causing a lump at this part of the armature coil, which is not quite as sightly, but for which there is always room.

In winding drum armatures it has been customary to cover the core heavily with insulation and place troughs of composite insulation in the armature slots in which the conductors are laid, but with some motors, notably the G. E. 800, the core insulation is omitted and the coils are more heavily taped. This has the advantage that it takes less time to prepare an armature core for winding, but it cannot be said to be as safe a winding as where the core and coil are separately insulated. Nevertheless, on account of its great convenience, it is becoming standard practice.

The Westinghouse practice is to have the coils wound in fullerboard cells, then the coils to go in the same slots are assembled in another cell of fullerboard and mica, and then the completed coil is taped with thin linen tape and dipped in an insulating compound. In winding the armatures, it is customary to put in troughs of thin fullerboard—not as insulation, but as protection against mechanical injury in working. For protection against lightning it is necessary to have the coils exceptionally well insulated before being placed on the core.

All drum armatures require band wires, a precaution not necessary in many ring constructions. The number and position of these bands are quite important. The fewer there are in the clearance space the better, and such bands as are required there should not be soldered more than is necessary to secure their ends, for they are revolving in a strong field, and the currents which are generated in them tend to flow at right angles to the wires of which they are constructed. If a path for these currents be provided in the shape of

a soldered connection, these eddy-currents may be very large and sufficient to heat the bands to a temperature at which the solder will melt, and it should, therefore, be used very sparingly. In the straight-out winding, bands which may be soldered together throughout their entire length may be placed outside the clearance, which may then be made as large as desirable. In fact, it is well in such cases to throw the

Fig. 61.—Method of Banding Straight-Out Armatures. Walker.

work of holding in the conductors as much as possible on these outer bands, the bands within the clearance serving merely to hold in the protecting fillers in the tops of the slots. This practice is well illustrated in the Walker armature shown in Fig. 61. A recent Westinghouse armature, shown in Fig. 62, has abandoned all bands in the clearance space, which is certainly an advantage if it can be made practical.

Modern railway armatures seem to prove that the formed coil has come to stay. The comparative cheapness with which it can be produced, the ease of winding an armature so constructed, and the general symmetry and durability of the result, are features which

no other method of winding has offered and which are especially desirable in railway work.

The armature cores of railway motors have been constructed in various ways. The ring armature of

Fig. 62.—Method of Banding Straight-Out Armatures. Westinghouse.

the Short Electric Railway Company was made by winding thin ribbon spirally upon a hub cast of composition and securely riveting it thereto. Slots were then cut in the sides of this built-up construction with milling cutters. The W. P. 50 and 30 armatures were made of punched disks built up on a suitable spider. When the drum armature became standard the earliest

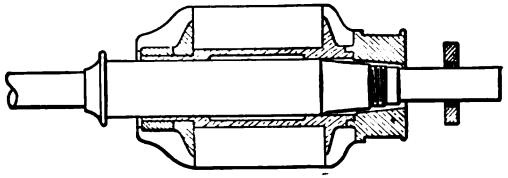

Fig. 63.—Early Walker Armature with Removable Shaft.

constructions used a threaded shaft with two nuts and end collars. An interesting modification of this was the early Walker armature shown in Fig. 63, in which the disks were assembled on a sleeve and the shaft was removable. The advantages of this construction

did not justify the added expense, and the later Walker armatures returned to the simple device of threading

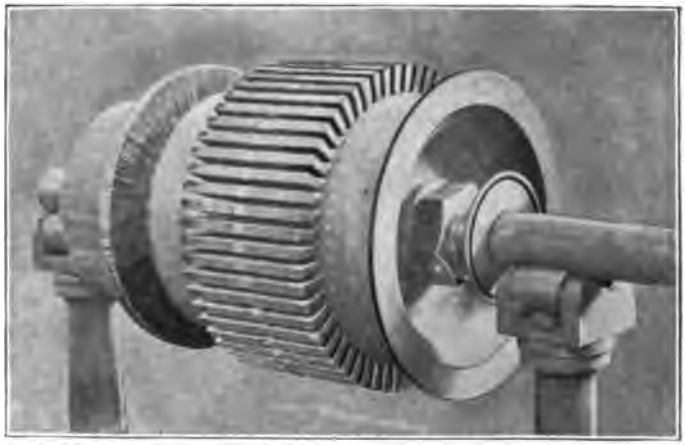

Fig. 64.—Walker Armature Core.

the shaft and securing the core disks thereon with nuts. Fig. 64 shows how the assembled core disks were thus secured.

Fig. 65.—Walker Armature Core Ventilated.

Ever since 1897 efficiency has been considered of great importance and every effort has been made to in-

corporate features in railway motors that would secure this result, and now modern railway armatures are supplied with ventilating ducts in the same way that generator armatures are fitted by the device of spacing disks set at suitable intervals. This is well shown in Fig. 65. The temperature at which modern railway windings are worked is so very high that this is a most necessary precaution. The standard practice of one prominent company is to employ a permissible heating limit of 75° centigrade above the atmosphere or 135° F. after a run of one hour at rated load. This, it will be readily seen, is very high, but the intermittent character of the work renders this permissible, and it may be said in general that railway motors are operated at a higher temperature than any other class of dynamo-electric machinery.

It is further worthy of note that the most recent railway armatures are smaller in diameter and have fewer slots and larger teeth than their predecessors. It is found to be much cheaper to wind several coils bunched together in a single slot than to distribute them in many slots; the core is less costly to construct, and the strong teeth are less liable to damage should they strike against the pole pieces.

CHAPTER V.

COMMUTATORS AND BRUSH HOLDERS.

EVEN after the advent of the carbon brush the commutator and brush holder remain one of the most difficult parts of railway motor construction. Railway armatures of necessity operate with fixed brushes, for even if means for adjusting their angular position were provided, it would not be possible to manipulate them when the motor was operating, and at such times only is any benefit to be derived from any change in their position. The rapidly varying load on the railway motor is always shifting the line of sparkless commutation, and even though good design may reduce the shifting to minimum, the conditions are very conducive to sparking. Dust and grit, which are always in close proximity, do not help matters, and brush holders and commutators must be built to stand this severe service.

Considering first the commutator, it is obvious that under these adverse conditions it should not be handicapped by poor material. Cast, or even tempered, copper is not to be recommended for this purpose. Drawn or drop-forged copper are the only suitable materials. Regarding insulating segments, continuous strips of mica are to be recommended. Built-up mica segments are not suitable, for they harbor conducting particles and frequently start a bridge between two bars which results in the destruction of the coils connected between them. It is surprising how a thin film of copper or carbon dust, scarcely equivalent to a No.

40 wire in circular milage, will suffice to burn out bobbins of No. 10 or even larger wires. The reason for this probably lies in the fact that the spurious conductor is exceedingly short, and being connected at either end with a massive copper commutator bar, the heat which is generated in it is rapidly conducted away, and even should the bridging film be deflagrated, an arc would be established between the bars which would be sufficient to destroy the coils connected between them.

The mica which is commonly used in commutators is of two kinds, namely, amber and India mica. Of these the India mica is best, electrically considered, but amber mica has advantages that render it more suitable. A mechanical consideration enters here. The commutator should wear down evenly, the segment as fast as the copper. The copper is subjected to an electrical gnawing action, due to small sparks as well as simple wear. If the mica segments are made too thick the bar will wear faster than the mica, giving the commutator an appearance like that shown in Fig. 66.

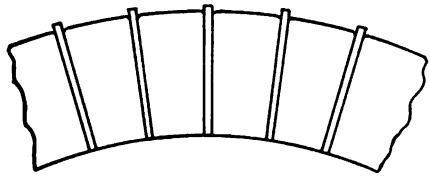

Fig. 66.—Wear of Commutator with India Mica Segments.

This difficulty once started will develop rapidly, for the more the mica segment protrudes the greater will be the sparking action at the bars. Commutators in which the mica segments are too thick come into the repair shop a grayish-black color, and on running the fingers over the surface the protruding mica segments

are readily felt. Often the segments protrude 1-32 of an inch or more. The gnawing action usually starts at the edge of the bar and works down beside the segment, as shown in Fig. 67. A short time suffices to

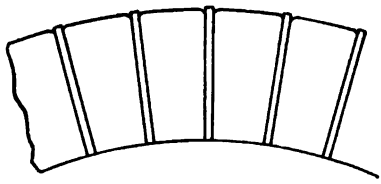

Fig. 67.—How the Action Begins.

wear down the intervening copper between, and the damage is done.

Modern railway commutators require a segment at least 1-32 of an inch thick. If this be made of amber mica it will wear down with the commutator fairly evenly, but in order to secure equally even wear with India mica the segment must be thinner, about .025 in. or .02 in., and either of these latter widths of segment are too easily bridged by carbon and copper dust. Necessity demands that India mica segments, to give best mechanical results, must be thinner than is good practice electrically, and therefore railway commutators built with India mica almost invariably have the faults just rehearsed.

The toughness of India mica is fully appreciated by those who have to turn up commutators. A commutator built of amber mica can readily be turned clear across its face with a single sharpening of the turning tool, but in the case of commutators built with India mica, the toughest tools lose their edge at almost the first turn of the lathe.

Built-up segments have a different and equally objectionable fault. They are too soft and wear down

faster than the copper, creating depressions in the commutator, which are easily filled with carbon dust, inviting a short circuit. This wear is well depicted in Fig. 68. Built up segments also are liable to break

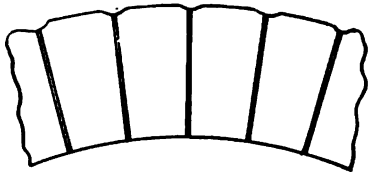

Fig. 68.—Wear when Segments are Too Soft or Too Thin.

apart with heat, so that a small piece will become brittle and drop out of the space between the bars, as shown in Fig. 69, leaving a hollow, which immediately becomes a receptacle for carbon dust and copper.

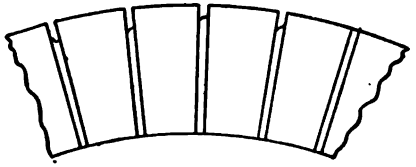

Fig. 69.—Wear of Built-Up Segments.

The carbon brushes which bear on a railway commutator should be frequently trimmed and squared. Failure to do this results in a bar worn as shown in

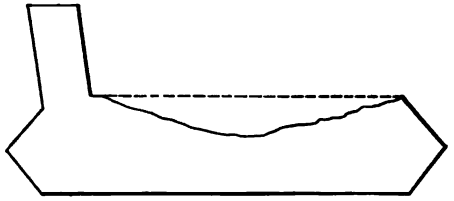

Fig. 70.—Wear of Bars with Neglected Brushes.

Fig. 70, and this curve becomes irregularly concave, so that it is almost impossible to fit a brush to it;

moreover, if the commutator wears evenly it will last longer. Commutator segments should be worn down to within ⅛ of an inch of their wearing depth before they are removed. It does not pay to go closer, as one of the bars might become completely worn through, and possibly cause a short circuit, which would call for a new winding as well as a new commutator. It is plain that as the commutator wears away the angular breadth of the bar becomes less, and a brush which at first bridged 1½ segment might easily bridge 2½ or more. In this way the commutated bobbin would be held under the brush too long, and the sparking difficulties, which are severe enough in any case, would be enhanced. As the commutator wears away the width of the brush should be proportionately altered, and especially is this true with deep commutators.

A popular way to build commutator bars is shown in Fig. 70, which illustrates the double bevel employed on the W. P. 50 machine. These bars will wear until they break through on the other side, but the pressure on the end collar may cause them to buckle or shift before their useful life is ended. The preferred form of bar to-day is shown in Fig. 71, and is now almost

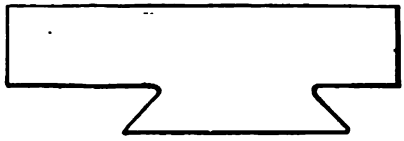

Fig. 71.—Modern Method of Securing Commutator Bar.

universally adopted. The grips hold this bar just as firmly at the end of its life as in the beginning.

A common way to build a commutator sleeve was once to have a large threaded collar, concentric with the shaft, pressing the beveled collar against the bars, but the preferred practice now is to force the collar

into position by means of six or eight screws suitably spaced about the end of the commutator. This latter method will prevent one section of the commutator

Fig. 72.—Method of Shell and Collar Arrangement.

being tightened to the exclusion of the others. Two methods of this kind are shown to good advantage in Figs. 72 and 73.

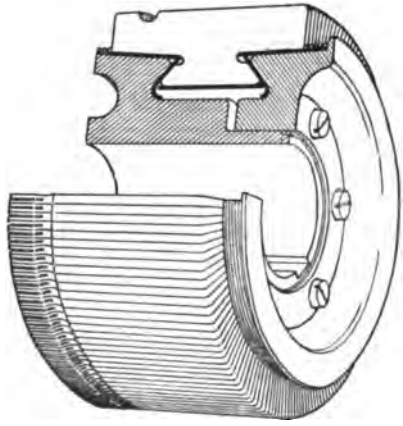

Fig. 73.—Method of Shell and Collar Arrangement.

It requires very little to provoke an arc on a railway motor commutator, and consequently extraordinary precautions have to be taken to prevent an arc being established between the commutator segments and the iron shell supporting them, for the latter is one of the

terminals of the motor. A popular method is to screw a vulcabeston collar on to the end of the commutator, as shown in Fig. 74, thus preventing the formation of

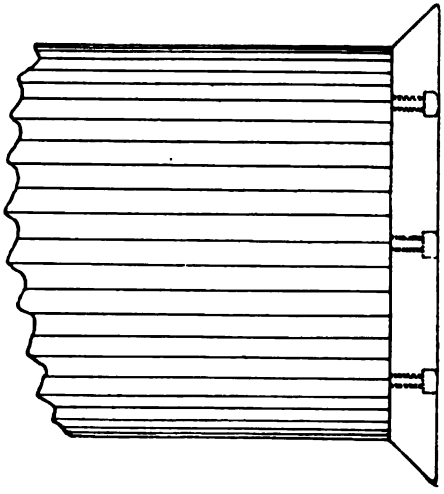

Fig. 74.—Vulcabeston Ring to Prevent Arcing.

arcs from the surface of the bar to the iron shell, except by a circuitous path. The method shown can be applied with suitable modifications to any commutator. Fig. 75 illustrates the method employed by the General Electric Company. In this method the collar is given a more intricate section and is very tightly held in place by a metal retaining ring, secured by machine screws.

Another method is to extend the mica collar, as shown in Fig. 76. This forms an effective fence to prevent the arc from jumping to the iron, but it is not mechanically so well adapted to rough handling. It has been used by the Westinghouse and Walker companies. With double bevel bars, the surfaces of which come flush with the end collar, it is frequently

good practice to wind a shellacked string protected with asbestos over the collar, as shown in Fig. 77. This is a favorite method and has been largely used by railway repair shops.

It is customary to line the parts of the motor casing adjacent to the brushes with sheets of insulating material, preferably vulcabeston or asbestos, to prevent

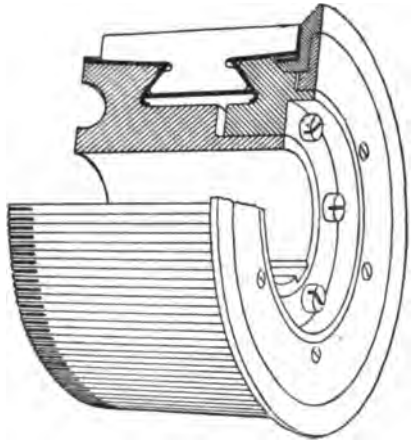

Fig. 75.—Method of Securing Vulcabeston Ring.

damage or grounding from the flaring arcs that sometimes occur at the brushes. These arcs are frequently due to weak fields, and often do a great deal of damage to the adjacent parts, especially to canvas-covered heads. For this reason commutator bars with lugs extending upwardly to the diameter of the armature, as shown in Fig. 76, are to be recommended. It will readily be seen that the surface of the armature adjacent to the brushes is of the same potential, and therefore destructive arcs will not find a circuit in the immediate vicinity. This practice demands a drop-forged copper commutator bar.

When drawn-copper bars are used, and they are

largely used on account of the lesser expense, it is customary to undercut them, as shown in Fig. 78. This makes a lug for the wire and enables the winder to con-

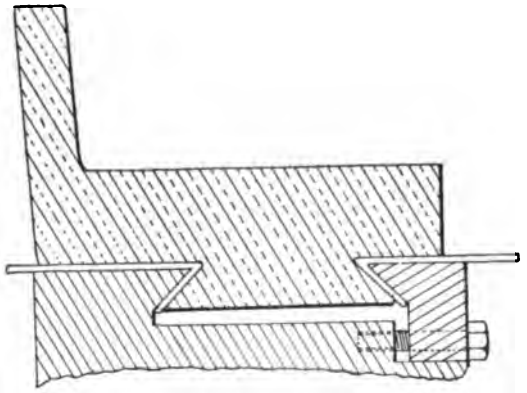

Fig. 76.—Projecting Mica Collar to Avoid Arcs.

nect up neatly, but unfortunately it demands a more or less combustible head next to the commutator.

In assembling commutators a good method is to take the prepared bars and stack them along the bench

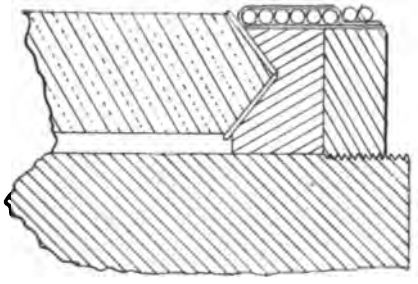

Fig. 77.—Insulating with String and Asbestos.

together with the segments which are to go between them. These segments consist of slips of mica which are gauged by means of a tool shown in Fig. 79. A sufficient number of slips are selected from a pile and

inserted in a slot in a gauge until a certain predetermined tightness is attained. This forms a segment.

All railway brush holders are almost identical in principle. They consist of a brass casting provided

Fig. 78.—Undercut Commutator Bar.

with suitable lugs for the connecting wires and a rectangular tube, which is radial to the commutator, and in which a single block of carbon rests. A spring-im-

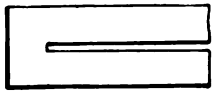

Fig. 79.—Gauge for Commutator Mica.

pelled finger presses the carbon against the commutator, and the holder is so designed that the pressure is practically constant throughout the life of the brush.

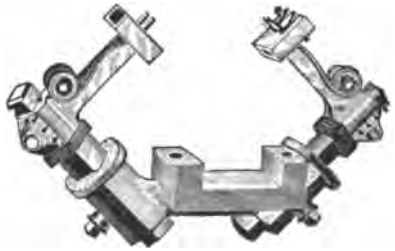

Fig. 80.—Westinghouse No. 3 Brush Holders.

There are two methods which have been employed for supporting brushes. One is to employ a protruding stick or rod of insulating material, on which the brush holder is mounted. With the W. P. motors these were

small sticks of wood let into mortises in the lower half of the case at diametrically opposite position on the

Fig. 81.—General Electric Brush Holder.

commutator. In the Westinghouse No. 3 the insulating support is secured as shown in Fig. 80.

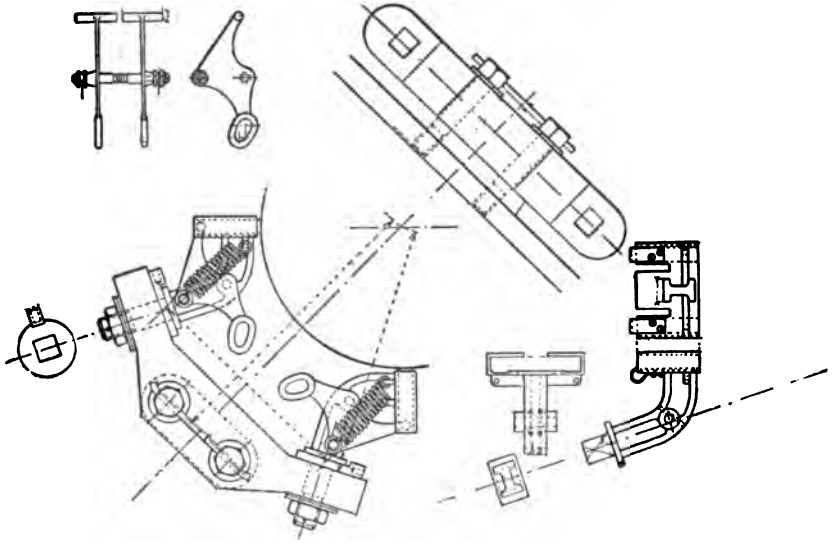

Fig. 82.—Brush Holder Used Abroad.

A method which is now finding favor is to fasten the brush holder to a vulcabeston board, which partly surrounds the commutator and serves to separate the brushes from the armature head. This board is fas-

tened to lugs cast in the upper half of the motor casing. Wood is sometimes used for this purpose instead of vulcabeston.

Fig. 81 serves to illustrate typical American practice and in Fig. 82 a brush holder mount of similar construction, that has found favor abroad, is depicted.

The Westinghouse Company have recently adopted the device of mounting the brush holders on studs bolted on to the casing by means of washers and bushings. This was tried in the early days of railway motors and abandoned because dirt was apt to bridge the distance between the casing and the stud. The Westinghouse Company, in using this device, have been careful to use liberal washers in order to minimize this possibility. The practice may be seen in the cuts of the newer Westinghouse motor cases in the next chapter.

CHAPTER VI.

MOTOR CASINGS.

THE modern railway motor is an entirely closed structure. Experience with the early motors soon proved that it would not do to have any part of the motor exposed to the dust, dirt, or moisture that was certain to accumulate on it in service. The first motor casings were of sheet metal or canvas, either partly or wholly covering the vital parts.

In the year 1891 motor designers began generally to appreciate the fact that the iron-clad type of field magnet was not only marvelously compact, but that no part of the inclosed case could be considered as idle metal, as it could be utilized for the return magnetic circuit.

The pioneer motors in this class were the famous Westinghouse No. 3 and Thomson-Houston W. P. motor, shown in Figs. 83 and 84. As we shall subsequently see, these motors only partly accomplish the object of complete inclosure, but they are exceedingly instructive as showing how the motor has developed, and why it is built as it is to-day.

The General Electric Company, at the time of its formation, was producing through its Thomson-Houston branch a railway motor known as the W. P. This was made in two sizes, the W. P. 50 and the W. P. 30, and the two motors were rated at 25 and 15 h. p. The letters W. P. stand for "water proof." The frame was cast in two halves, which hinged together over the car axle, and were secured by the hinges on the one side and by two bolts in the

edge of the casing on the other. The lower half was shaped like a bowl with a plow-nosed bottom, which would deflect obstacles on the track to the right or left. This motor was one of the first to use the yoke suspension, which consisted of a bar bolted to the case and suspended at the ends on springs resting on the truck

Fig. 83.—Westinghouse No. 3.

side frames. The seats for the bar and the bolt holes can be readily seen in Fig. 84.

The bearings were cast integral with the lower half and are lubricated by grease cups from above. The motor has but two pole pieces, one in each half. The upper is salient and carries a coil; the lower is consequent and without a coil. This has an advantage in that there is no field coil in the lower half of the case where dust and moisture are sure to accumulate. The upper half of the casing has two semicircular openings,

one over each bearing, to facilitate inspection. The brushes, which are two in number, are set on opposite sides of the commutator in line with the parting of the casing. The commutator bearing of the W. P. motor is admittedly too small, both in diameter and length. The motor was originally built for narrow-gauge work, which in part accounts for its abbreviated bear-

Fig. 84.—Thomson-Houston W. P. 50.

ings. The liners of the bearings are preferably made of brass shells ⅛ inch thick, and they may be allowed to wear 1-16 of an inch before renewal.

The large openings on either side of the upper half of the casing serve admirably the purpose for which they were intended, and they ventilate the motor so that it can carry enormous overloads, but unfortunately they admit dust and water to such a degree that some kind of a covering is absolutely necessary. These covers are usually canvas or ruberoid motor curtains, and occasionally they are made of metal. All things considered, the W. P. motor was the earliest exponent of the iron-clad field frame, and the principle of the two bowl-shaped halves is now universally used to-day.

Contemporary with the W. P. motor was the No. 3 motor of the Westinghouse Company, shown in Fig. 83. It will be readily seen that this is by no means as typical of modern inclosed practice in casings as was the W. P. It consisted simply of a multipolar frame swung in a rectangular yoke, which the Westinghouse

Fig. 85.—Intramural Motor. General Electric Company.

Company at that time considered a valuable feature and which it had previously used on its old bipolar forms. The necessity of closing up the openings in the bottom part of the field frame was soon realized and carried into practice, as shown in Fig. 83. The upper half of the motor was left open, and therefore it possessed the same characteristics with regard to carrying overloads as the W. P. 50 and 30, and required

similar protection. The lesson of ventilation has not been lost, and wherever the service permits, such as over stone-ballasted roads and elevated railway work, modern casings are left open. The increased capacity which this additional ventilation secures is of great advantage in the larger sizes, where much power must be placed in limited space. This principle is well illustrated by Fig. 85, a cut of the intramural motor used

Fig. 86.—Thomson-Houston S. R. G. Motor.

at the World's Fair and due to the General Electric Company.

The W. P. motor was perhaps the first of the inclosed motors of modern practice, though its contemporary, the Westinghouse No. 3, certainly of earlier date, also claims first honors. The latter motor was a plain multipolar frame swung in a yoke and did not quite as closely approximate the bowl-shaped castings of to-day as did the W. P.

By many the S. R. G. motor, shown in Fig. 86, is thought to be superior in all-round qualities to its successor the W. P. 30. It is interesting because it

was the first single-reduction motor to be placed upon the market, and the letters S. R. G., without other qualifications, invariably refer to this motor. It remains to be said, however, that the Westinghouse No. 3 motor is the unquestionable pioneer in the adoption of the internal radial pole field with four salient poles and the two-circuit multipolar drum winding which are universally used to-day.

An interesting early motor is that of Professor

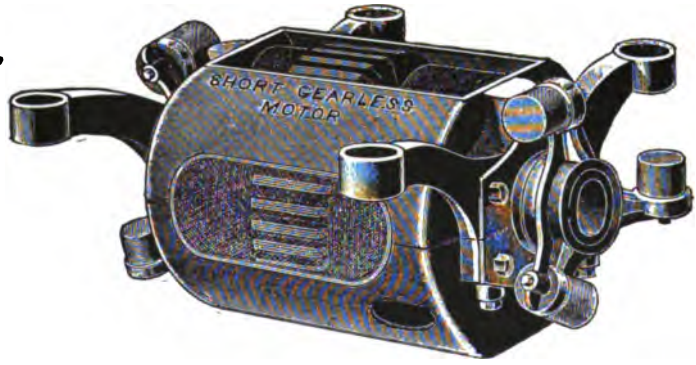

Fig. 87.—First Form of Short Gearless Motor.

Short, who adapted the Brush form of field magnet to railway work. This form of field was very heavy for the output of the armature it magnetized, and had other inherent disadvantages. In spite of this fact, motors were produced which were excellent for that time and created sharp competition. The last form of single reduction motor made became very popular, and many of them are running to-day.

Perhaps the most interesting of Professor Short's early motors were his gearless types, in which the motor was connected directly to the car axle. One of the first of these is shown in Fig. 87. In form of field magnet and general inclosure it bears a strong resemblance

to the single-reduction motor, which was the most brilliant commercial success of the Short Company. The Brush form of field magnet was finally abandoned in favor of the type shown in Fig. 88. This is a six-

Fig. 88.—Last Form of Short Gearless Motor.

pole field of the form shown in Fig. 8, and had a ring armature with a tubular shaft through which the car axle was threaded. The winding of the armature was on a series plan, so that only two brushes were needed and these were opposite. The six-pole field, the tubular shaft, the flexible connection to the car axle, and other advantageous features formed the basic claims of a series of foundation patents which are now the property of the General Electric Company. Under these patents the latter manufactured the immense gearless motors used on the Baltimore and Ohio electric locomotives. These motors, illustrated in Fig. 89, are rated at 320 horsepower, and are the largest electric railway motors in the world.

Another motor which reached the height of its com-

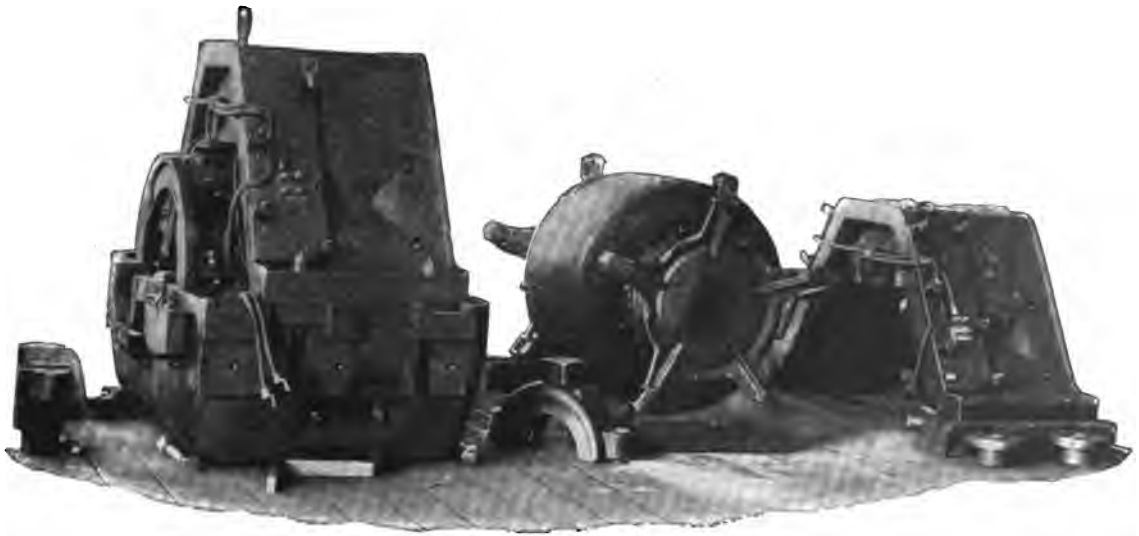

Fig. 89.—Baltimore and Ohio Locomotive Motors.

mercial fame soon after the advent of the Short motor was that of Sperry. This motor is illustrated in

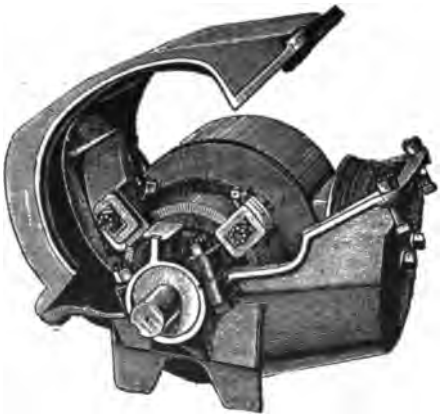

Fig. 90.—Sperry Motor.

Fig. 90. It was a four-pole motor with two salient and two consequent poles, the coils being on the hori-

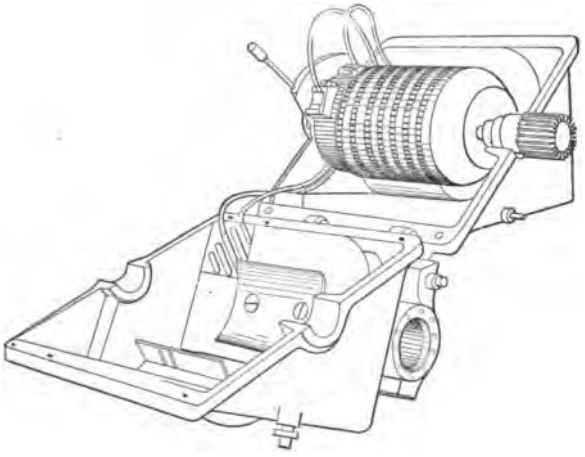

Fig. 91.—Siemens & Halske Motor.

zontal poles. This was permissible because the case parted diagonally, and thereby the line of division

avoided them. This ingenious method has been practiced abroad in the railway motors of Siemens & Halske (see Fig. 91). This diagonal parting has another advantage, because a four-pole motor having the salient poles horizontal could have much larger dimensions than if the salient poles were vertical, because of the greater clearance space between the axle and the roadway. Another feature of interest of the

Fig. 92.—G. E. 800 Motor, Closed.

Sperry motor was its peculiar connection to the car axle by means of bevel gears. This is taken up in the chapter on gearing.

The first production in the line of railway motors of the General Electric Company as a consolidation was the G. E. 800, and its success will ever be remembered by all those who had to do with railway work at that time. It introduced a number of radically new features, and is illustrated, both open and closed, in Figs. 92 and 93. It has perhaps the first entirely inclosed motor casing and contained many of the characteristics of its predecessor, the W. P., being similar

in armature proportions, and in the fact that its armature bearings were bolted to the lower half of the field casing. They were lubricated by grease cups cast in the bearing caps.

The trouble with refuse lubricant had evidently begun to be appreciated, for in this motor pockets leading

Fig. 93.—G. E. 800 Motor, Open.

to the outside of the casing were cast directly under the edge of the bearings, and were intended to catch all refuse lubricant. The convenience of being able to remove the motor from the car axles without opening the casing became apparent, and accordingly the axle bearings were cast on brackets projecting from the casing, and the caps of these bearings were separately removable from above. There were two coils, one above and one below the armature, and four poles, two

of which were consequent. This arrangement has the disadvantage of having one of the coils in the bottom of the field casing, where it was liable to receive damage from waste lubricant, dust or water, which would sometimes accumulate even when the greatest precautions were taken. The later motors used the device of sealing up the lower field coil in a sheet-lead receptacle, which is an effective improvement. The armature must be removed from above, which is somewhat inconvenient, a defect that has been remedied in the later designs.

The case is secured together by bolts on the back and front. The door over the commutator gives access to the brushes, and the upper half of the field casing can be very readily opened. It has been customary to make the commutator door of this motor casing tight by means of a felt gasket. The motor utilized what is known as the nose suspension, a suitable projection, engaging with the spring-supported crossbar. The bearings are lubricated by grease cups on the caps, the feeding being by gravity only. The shells are babbitt lined, the pinion being 2½ inches by 6 inches and the commutator bearing being 2½ inches by 4½ inches. On similar lines to those of the G. E. 800 are modeled the G. E. 1200 and the G. E. 2000. The G. E. 2000 motor is shown in Fig. 94.

About one year after the advent of this series of motors the General Electric Company produced a motor involving radically different features of design known as the G. E. 1000, and which quickly demonstrated its superior qualities. This motor has already been illustrated in Fig. 37, in the chapter on field coils. It is shown with the casing closed in Fig. 95. This motor abandoned the consequent-pole form and adopted the now standard form of four salient poles,

each carrying a coil. The bearings are arranged to be lubricated either by grease cups from above or from oil wells with felt wick wipers from below, and this method of lubrication is now standard among all makers. The axle bearing brackets are cast on the upper half of the field casing, which enables the lower

Fig. 94.—G. E. 2000 Motor.

half to be swung downward with or without the armature by the simple device of having the bearing bolted to the upper half or not, as might be desirable. This is a decided advantage, for it is much easier to dismount a motor from beneath by running the car over a pit than to renew the parts through a trap-door in the car flooring, as the latter operation usually necessitates some form of crane with a long boom which can be projected into the car through a door or window. Moreover, the dismantling of a motor from within the car was seen to be detrimental to the finish and upholstering of the car interior unless extreme care is taken.

The bearings are arranged so that both ends are outside the motor casing, thereby permitting refuse lubricant to drop on the ground and not enter the motor. The door over the commutator, instead of being hinged, was changed into a lid secured with hinged

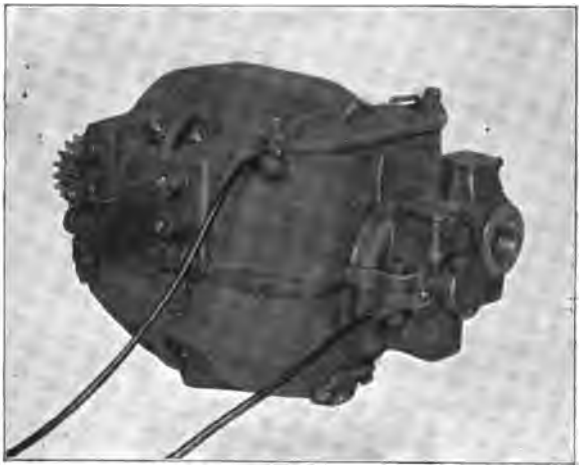

Fig. 95.—G. E. 1000 Motor.

bolts, which enable it to be very tightly secured yet readily removed.

It is interesting to note that these ratings, 800, 1000, 1200, and 2000, refer to the draw-bar pull in pounds with the equipment mounted on 33-inch wheels and traveling at the rate of 10 miles an hour. On the lines of the G. E. 1000 motor has been designed the G. E. 52, which is slightly more powerful than the G. E. 800, and which has replaced it. This motor is shown open in Fig. 96. It is interesting to note that the corner plates of the G. E. 1000 field coils have broadened out, and in subsequent types, as has been already mentioned, complete field spools are again used. Attention is also called to the hand hole in the

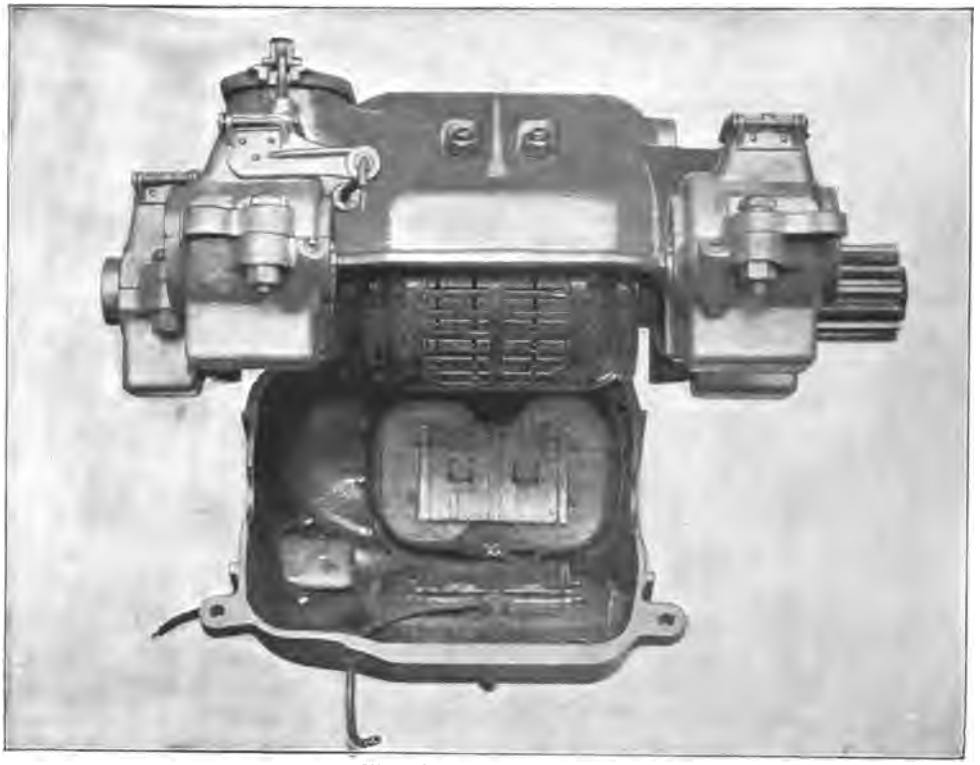

Fig. 96.—G. E. 52 Motor.

lower half of the casing under the commutator to facilitate the removal of foreign substances and examine the clearance as the bearing wears away. The poles are made of bunches of laminated plates drilled and countersunk and screwed to the casing by bolts. This is also the method used in the G. E. 1000 motors, and has many advantages, for it permits the use of a pole

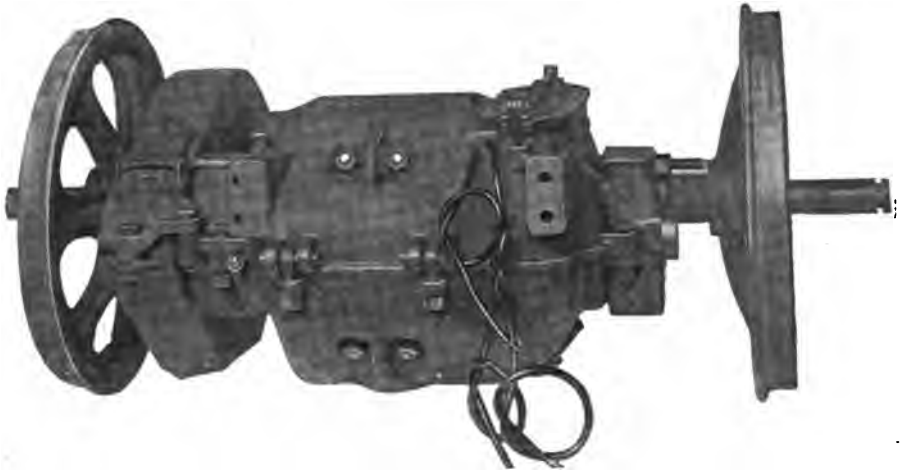

Fig. 97.—G. E. 57 Motor, Front View.

piece and consequent economy in the magnetizing coils, and it eliminates eddy currents in the pole pieces, a fruitful source of loss in earlier motors. In respect to bearings, and indeed in many other features, the general arrangement of the G. E. 52 motor is that of a G. E. 800 turned upside down.

The device of using four salient poles is generally admitted to be superior. There are more field coils, it is true, but the lowest part of the motor casing, where destructive fluids are liable to accumulate, is now clear of the field coils, and by means of a hand-hole in the bottom of the case foreign substances can be readily removed.

Another improvement in this class of motor appears in Fig. 97, which is a view of the G. E. 57 motor, a

Fig. 98.—G. E. 57 Motor, Rear View.

larger size. This improvement consists of a hinged joint which is made adjustable by means of nuts, thus

Fig. 99.—G. E. 51 Motor.

enabling the casing to be tightly drawn together and insuring a good magnetic joint between the bowl-shaped halves.

As the larger sizes were reached, the space between armature shaft and car axle became limited and a matter of serious import to the designer. Space was gained by enlarging both pinion and gear, but even so,

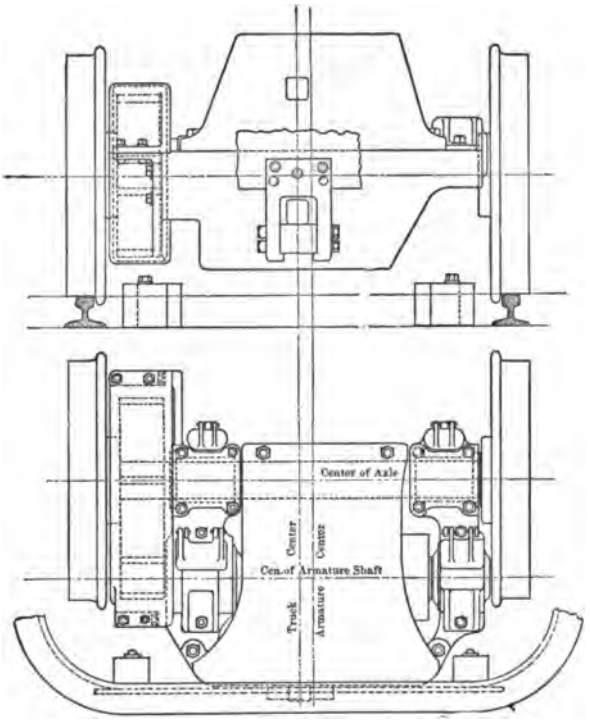

Fig. 100.—Walker 25 L, Plan and End Elevation.

other expedients were necessary. Thus the G. E. 57 motor has a recess in its casing to accommodate the car axle, as shown in Fig. 98, while in the G. E. 51 motor shown in Fig. 99, and in the Walker No. 25 motor shown in Fig. 100, the car axle is actually included in the motor casing. A sketch of the side elevation of this latter motor, shown in Fig. 101, shows

how the pole pieces were displaced at an odd angle to make room for the car axle.

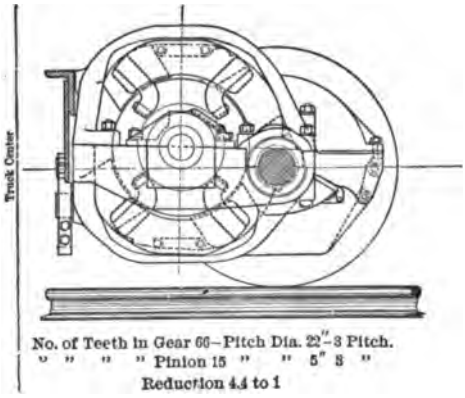

Fig. 101.—Walker 25 L, Side Elevation.

The Walker motor was the last American product to enter the field of competition, and it attained its

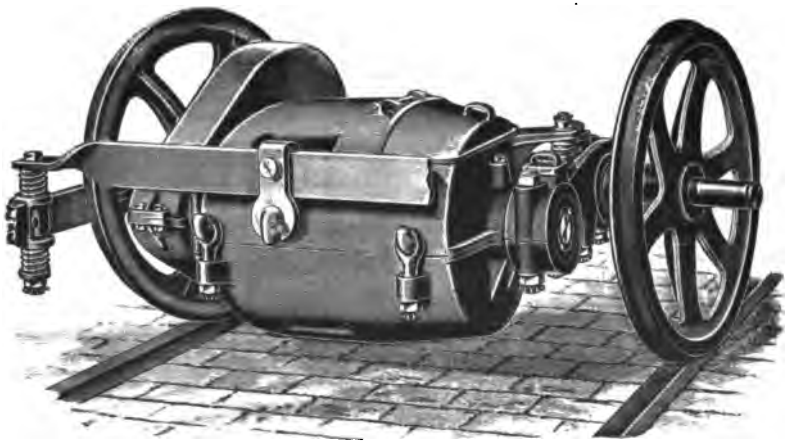

Fig. 102.—Early Walker Motor.

state of development at a bound. The earliest type, which is shown in Fig. 102, will be seen at once to in-

clude in its motor case all the features which the modern products of others possess. It has been changed only in detail. Its peculiar suspension renders direct comparison a little difficult. It will be seen, however, that the axle bearing has its cap removable from below, and is lubricated by grease cups from above, in the

Fig. 103.—Later Form of Walker Motor.

usual way. The features of the casing will be more readily understood from the cuts of the more modern type. Figs. 103, 104, and 105 show them to better advantage, and they involve several new principles. The details of the suspension will be taken up in another chapter, and need no extended discussion here. The armature bearings can be retained in the upper half of the motor, or allowed to fall with the lower half, by the use of a little auxiliary bolt, which, when screwed in place, fastens the bearings of the upper half to the casing.

The bearings are all lubricated by grease cups in the

suspension arms. The bearings, although cast integral with the motor casing, are arranged so that both edges are entirely outside, and the use of a generous oil flange on the armature shaft effectually prevents any grease from entering the casing. This arrangement is shown in Fig. 106, depicting a section of the casing. This improvement is now universally used.

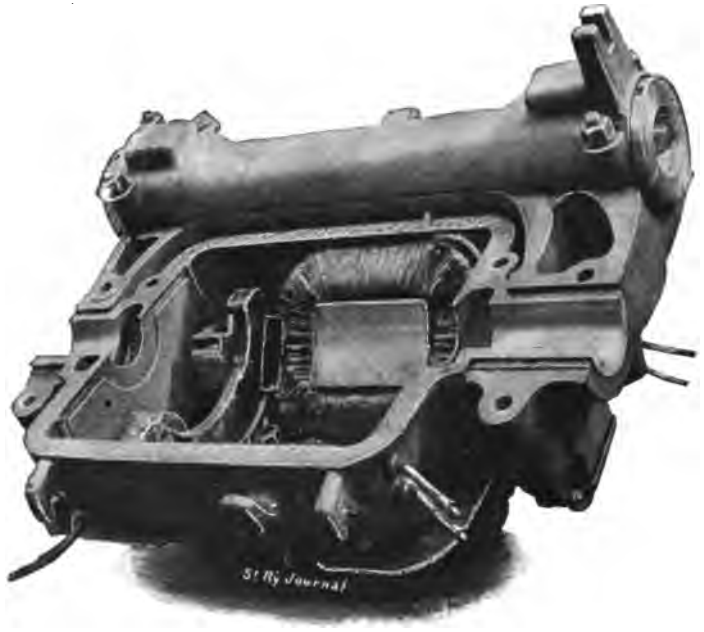

Fig. 104.—Walker Motor. Top Half of Case.

The hinge is also a unique feature and a decided improvement over any other. In Fig. 107, in the upper half of the casing, will be seen two projecting hooks. These engage with an elliptical eyebolt, which is secured to the lower half of the casing. This not only acts as a hinge when the lower half is swung down into the pit, but also permits of drawing the casing tightly together, and further permits the operator to readily

detach the lower half by simply unhooking it from the upper one.

Two bolts and two hinges hold the casing together and are supplemented by four other bolts, which secure

Fig. 105.—Walker Motor. Lower Half of Case.

the armature bearings. The armature bearings are really a bearing within a bearing, for the case turns in the suspension arms to a certain extent. This motor

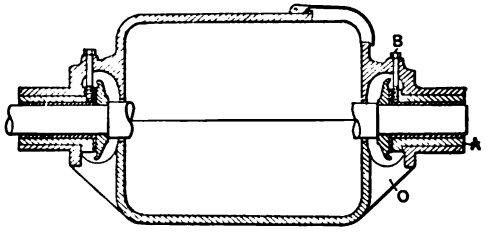

Fig. 106.—Section of Walker Motor.

is provided with a door over each end of the armature. As the commutator end is the more frequently inspected, it is provided with a hinge door. The door at the other end is secured by a bolt. The pinion bearing of the Walker No. 3 motor, for that is the

name by which this type is generally known, is exceptionally long, being 8 inches in length.

The Walker motor is one of the few modern motors for street railway service which attempts to secure ventilation of its casing. This is accomplished by holes in the covers passing diagonally upward. These

Fig. 107.—Last Form of Walker Motor.

holes are really tubular openings, for the inlet inside the case is several inches above the outlet on the surface. In this way air is admitted without dust and water. There are four such openings, two in each cover. This was abandoned later, and the simple lid was again used, as shown in Fig. 107. The space under the commutator is easily accessible by means of a hand hole, and through this orifice the clearance can be measured by a taper gauge. The clearance can also be inspected with greater facility in a novel manner. Two peep-holes are bored in the casing and are normally closed by plugs. On unscrewing the latter and holding a lighted candle in front of one of the peep-

holds the clearance can be easily seen by looking in the other.

The Walker No. 20 motor shown in Fig. 108 is rated at 125 h. p., and is typical of the No. 15 interurban motor rated at 75 h. p. The difference between

Fig. 108.—Walker Interurban Motor No. 20.

the two consists in the fact that the smaller motor is inclosed by cast-iron covers over the two spaces above and below the bearing on either side. The No. 20 shows the construction of this type to better advantage, and is therefore illustrated.

The motor is parted on a line inclined from the horizontal. It is held together by two pivot hinges in the rear and bolts in the front. It is of the consequent-pole type, four poles, and two coils above and below the armature. The four armature bearing bolts also hold the case closed. The hinge pivots can be readily removed, if it is necessary to take the casing com-

pletely apart. The motor clasps about the car axle, as in such large sizes it is necessary to have the axle very close to the casing. The cover over the commutator opening is hinged, and those over the four other apertures are bolted on. These four openings make this motor very accessible.

The bearings are babbitt-lined, with cast-iron shells. They are lubricated by grease cups above them. This

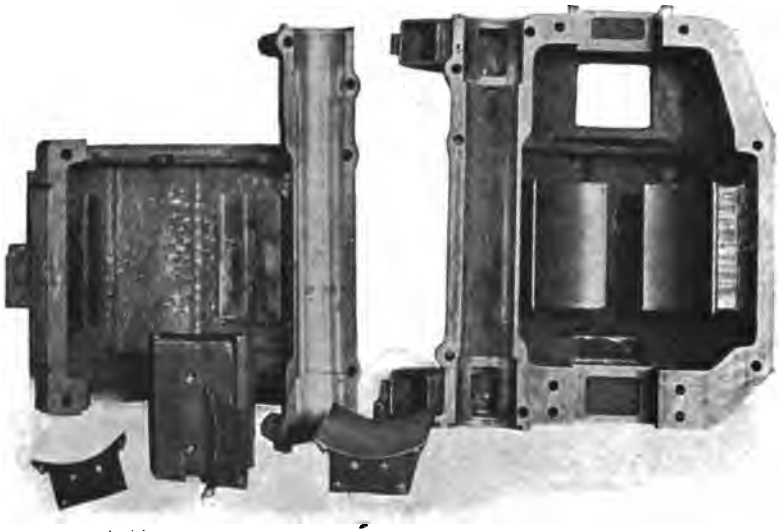

Fig. 109.—Casing of Walker No. 20 L.

motor is intended for service over roads where the traction is severe, but where trouble from dust and mud is slight. It is, therefore, simpler and more rugged than the average railway type, but less elaborately provided with guards and arrangements for easily taking the motor apart. From this it is by no means to be considered that dismantling this motor is a difficult task. It is in about the same class with the G. E. 51, and is intended for similar service.

In the later types of Walker motor the laminated poles were adopted. In these motors the poles were bolted on projections cast in the casing. The metal next the bolt holes in both the pole pieces and the casing was machined away, thus insuring a

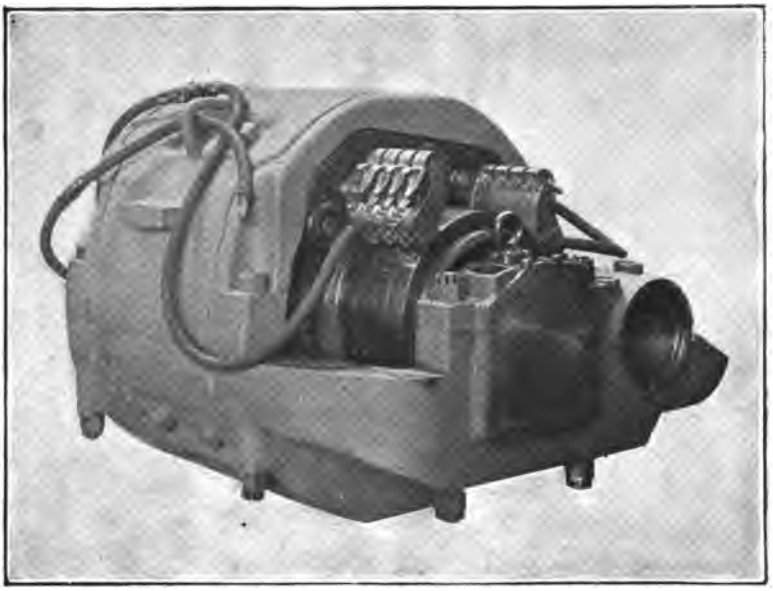

Fig. 110.—Walker No. 20 L Motor.

metal to metal contact between the surfaces. The casing of the No. 20 L motor is shown in Fig. 109, and it is very like that of the No. 15 L, except that it is larger. It is interesting because it illustrates a recent practice in motors for elevated service, that of making the lower half closed and using an open upper half or compromise between the entirely closed and the open forms. In Fig. 110 the No. 20 L motor complete is depicted.

The Westinghouse Company has been developing the inclosed motor since 1891. Its first attempt was

the No. 3, which appeared shortly after the S. R. G. This motor, shown in Fig. 83, was a radial internal-pole machine, mounted in a rectangular yoke, which was fitted on the car axle. The upper half of the field was secured, as shown in the figure, by a hinge on the yoke, and the lower half can be swung in a

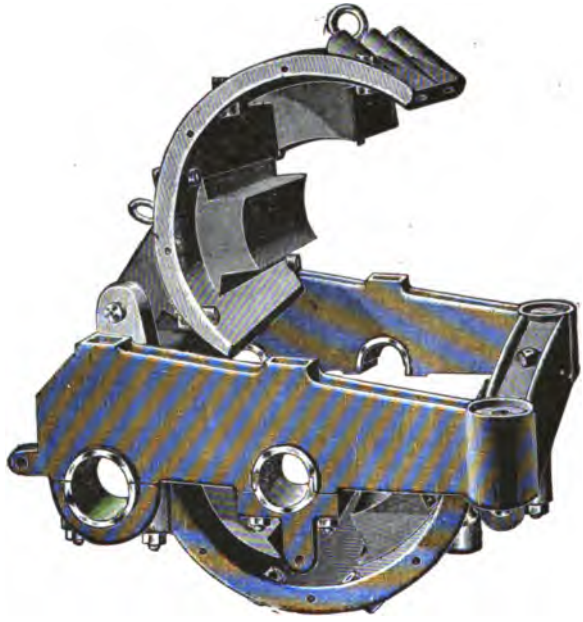

Fig. 111.—Casing of Westinghouse No. 3.

similar manner, but in the opposite direction, by a hinge on the lower half. The bearings of the motor are in the yoke arms. The two halves of the field magnets are bolted together by four bolts, the hinge joint simply connecting the field frame to the yoke which carries the armature bearings. The yoke is cored out hollow for the sake of lightness. The openings in the lower half of the motor case, if such it can be called, are closed by semicircular iron plates, bolted

to the field frame. These bolts may be removed for measuring the clearance or clearing out the motor case, and have been found extremely convenient for that purpose. Indeed, it is probable that from these removable plates the bottom hand-hole, utilized in the more modern Westinghouse types, has developed.

Fig. 112.—Westinghouse No. 12 A, Open.

The bearings are lubricated by grease cups placed over them and cast into the yoke. There are four poles, all salient. The commutator is readily accessible, as it projects beyond the field frame and is outside the casing. The bearing caps are removable from below, a feature which is considered desirable in modern motors, and is a distinctive feature of this early type. In the top of the field frame are two semicircular openings which were intended for ventilation, but, like those of the W. P., are preferably closed by a canvas or

sheet-metal covering. The details of the field frame are better seen in Fig. 111.

The No. 3 was superseded by the Westinghouse No. 12, and that in turn by the No. 12 A. The 12 A differs so slightly from the No. 12 in the general features of the casing that the more modern type only will be described. It is shown open and closed in Figs. 112 and 113. It is adapted to either the nose, side-

Fig. 113.—Westinghouse No. 12 A, Closed.

bar, or cradle suspension, straps being cast upon the side of the upper half of the case to accommodate the two latter suspensions. The case is parted in the middle and is secured on the one side by an eyebolt hinge and on the other by the four axle-bearing bolts. The hinge is not, strictly speaking, an eyebolt hinge, as will be seen from Fig. 113, but that device is used on the Westinghouse No. 38 B, a 50-h. p. motor. The motor is lubricated by grease cups above, and the armature bearings are entirely without the motor. Fig. 112 shows this arrangement to very good advantage. The armature may be retained in the upper half of the case, when the lower is swung

down by use of special hook bolts, which are adjusted to surround the bearing before the case is opened.

The axle bearing caps bolt on from below, brackets being cast on the upper half. All the bearings are cast-iron shells, babbitt-lined. A hand-hole, closed by a bolted cover, is provided in the bottom of the case. The poles are four in number and each carries a coil.

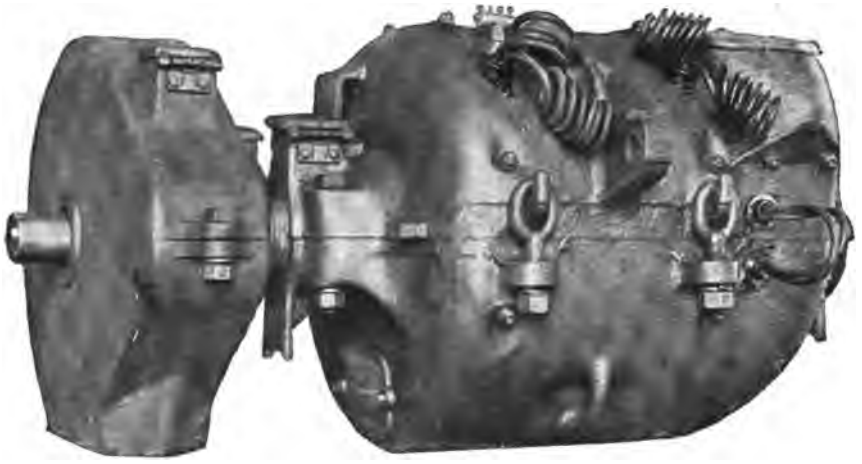

Fig. 114.—Westinghouse No. 38 B Motor.

The motor is fitted with the usual door over the commutator.

The Westinghouse No. 38 B, a 45-h. p. motor, differs from the No. 12 A in that the field castings are of steel and the pole pieces are laminated. It weighs but little more than the No. 12 A and is shown in Fig. 114.

The latest type of motor brought out by the Westinghouse Company is the No. 56, shown in Fig. 115. It differs from its predecessors in several important details. The bearings are very long, adapted for use with both grease and oil. The pole pieces are laminated and bolted on, as shown to advantage in Fig.

116; the brush holders are mounted on studs bolted into the casing. This motor is designed for heavy

Fig. 115.—Westinghouse No. 56 Motor.

service. An interesting minor feature is the ground screw or connector for the ground wire. It is usually

Fig. 116.—Westinghouse No. 56, Lower-Half of Casing.

thought sufficient to slack off a bolt on the truck or motor frame and loop the ground wire about it; but in

the motor shown in Fig. 115 a separate terminal is provided threaded in a hole tapped in a boss on the field casting.

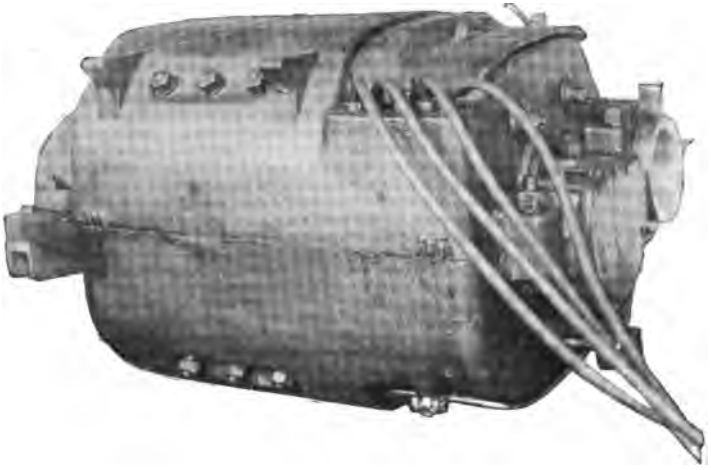

Fig. 117.—Westinghouse No. 50 C.

The Westinghouse elevated railway motor, the No. 50 C, is illustrated in Figs. 117 and 118. This motor differs from most in its class in that the casing is

Fig. 118.—Westinghouse No. 50 C, Rear View.

closed. It is lubricated by oil only, and, as in all of the larger motors, the car axle passes through the motor

case. The hand hole at the base of the motor is now developed into a substantial cover, which makes the commutator very accessible without opening the cas-

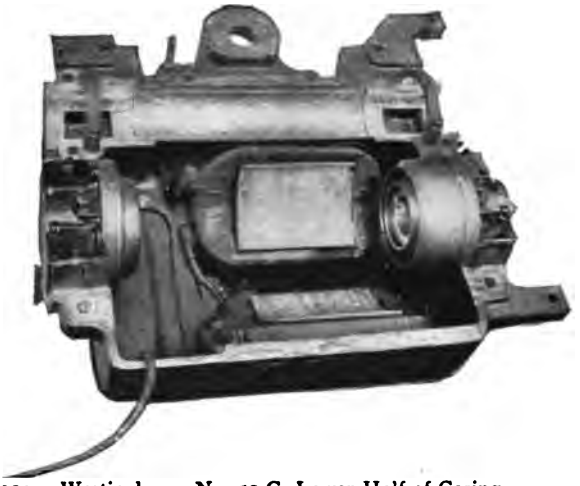

Fig. 119.—Westinghouse No. 50 C, Lower-Half of Casing.

ing, and as the latter operation is a matter of some difficulty in motors of this class this is important. The brush holders are supported on studs as in the No. 56, and the leading-in wires enter at a plane surface conveniently located and specially cast for them. Another important feature of this motor, and one conducive to great economy of space, is the bearings, which are literally inside the armature. This shows to good advantage in the cut of the lower half of the casing, Fig. 119.

Another American manufacturer, known as the Lorain Steel Company, is supplying what is known as the "Steel motor," which was made in several forms by two other companies before their interests were transferred to the present makers. The first of these was a consequent-pole motor, shown in Fig. 120. This has been since superseded by two new motors of more

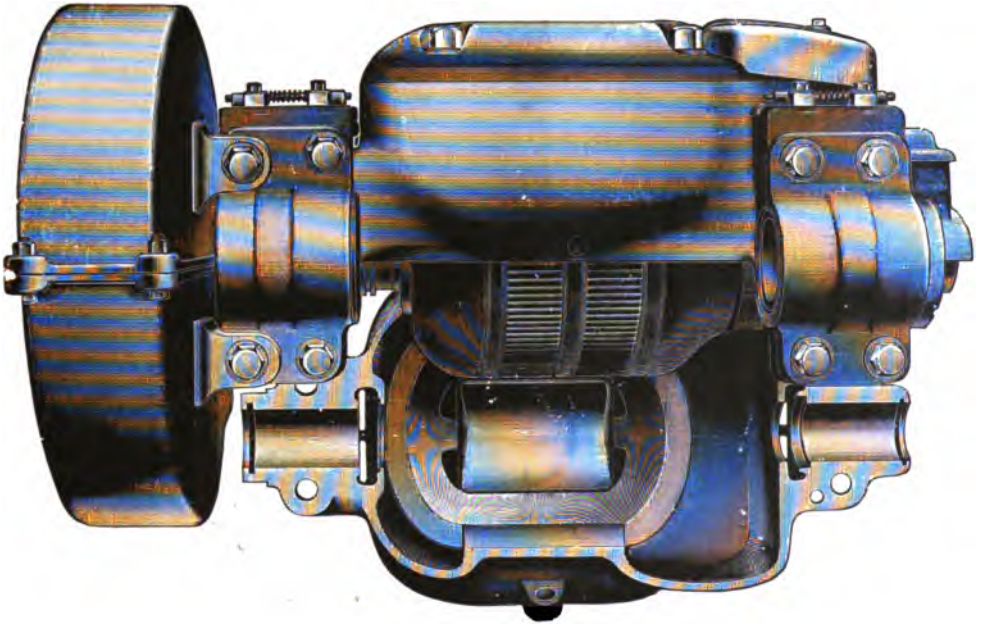

Fig. 120.—Early Steel Motor.

modern design. These sizes are No. 20, of 25 h. p., and No. 34, of 50 h. p. With regard to cases, these motors are so alike, with the one exception of dimensions, that a general description of the No. 20 will suffice.

The motor cases are aligned by dowels, and are secured by the armature bearing bolts, which pass

Fig. 121.—Motor of Lorain Steel Company.

through cored holes. The case is suitably cast to accommodate either the nose or the sidebar suspension, and there is no hinge to the casing. The halves of the casing are chained together by a link support. The lubrication is very profuse. Grease cups above, and oil wells with appropriate wipers below, are employed. The bearings are cast-iron shells and are interchangeable, except when a 30-inch gauge is used. In that case the commutator bearings are a little shorter. The usual cover over the commutator is provided. The armature may be retained in either half

of the casing on opening the motor, by bolting the appropriate shank of the double-shanked eyebolt, the

Fig. 122.—Motor of Lorain Steel Company.

eyelet of which surrounds the armature bearings. The axle bearing brackets are cast to the upper half and the caps are removable from below. Figs. 121 and

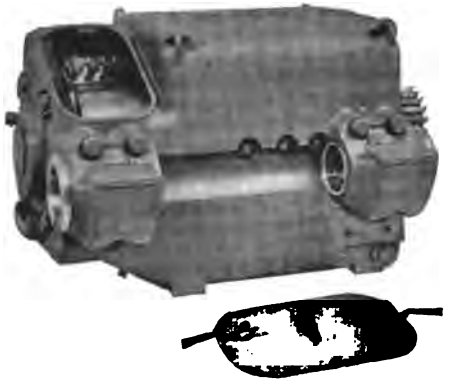

Fig. 123.—G. E. 55 Motor.

122 will assist in more readily understanding the description of the motor.

A new motor which is a radical departure from recent American design has been placed upon the market

by the General Electric Company. This is the No. 55 and it is illustrated in Fig. 123. It has been designed with a view to getting a great deal of power into a small space, and to do this the feature of a separable case has been sacrificed. The casing consists of a cubical casting, and it is bored out with a single cut of the boring bar, thus serving to face the pole seats and the seats for the end bearings. The armature is removed from the ends, which are normally closed by the bearings. The latter are cast in the center of large circular plates and are let into the casing so that their outer ends come flush with the outside. The straight-out winding and the overhung commutator render this permissible. The motor is rated at 160 h. p., and will doubtless replace the G. E. 2000. The poles are laminated and bolted to the casing, and it is otherwise provided with the latest improvements in electric railway motor construction.

CHAPTER VII.

MOTOR SUSPENSIONS.

It is not possible to justly estimate the value of the various systems of suspension now in use, without considering the action of a loaded truck as it travels over a rough track. Inasmuch as many users of railway motors have not looked into this matter, other than superficially, this chapter is prefaced by a brief review of the action of a loaded truck.

Let us suppose that we have a single pair of wheels, around the axle of which is bolted a heavy cylindrical casting, such that the center of gravity of the system is practically the center of rotation. Place these wheels upon a track and set them in motion. So long as the track is level and there are no sudden depressions or elevations in its construction, the wheels will roll smoothly and steadily along it, but if a slight obstruction be encountered, either a depression between two rail ends which are somewhat widely separated, or an elevation due to lack of exact alignment, the wheels thus loaded will jar heavily as they pass over the obstruction, and there will be between the track and the rim of the wheels at that point an impact which is composed of two distinct actions. The first is that of ordinary impact. If a moving body meet an obstruction, the collision is sure to deface one or the other to a certain extent. The second effect is due to the fact that in striking an obstruction the center of gravity of the moving mass is suddenly lifted. If the speed of the wheels be anything like ordinary street-car

speed, the time in which this lifting takes place is almost instantaneous.

This will impart to the mass of the motor and car wheels an upward velocity, which, combined with its weight, will produce an enormous momentum. To take a hypothetical case: Suppose that the dead weight of the wheels on the track is 1000 pounds, that the center of gravity is raised .1 inch, that the obstruction is ½ inch in length, and that the wheels are traveling at the rate of 10 miles an hour. These are easily possible conditions. Two rail ends may be out of line .1 inch, although that is quite an excessive amount. Ten miles an hour is very common speed for car wheels, and it is quite probable that in this case the wheels would have to travel ½ inch before they could be fairly off one rail and on another. At 10 miles an hour the wheels would surmount the obstruction in .00284 second. This means that the center of gravity of a weight of 1000 pounds would be lifted upward at least .1 inch in that time, and its velocity upward would therefore be approximately 3 feet per second. It is difficult to deduce a mathematical quantity which shall be a measure of the defacing action of impact and it will not be attempted to discuss the matter in a quantitative manner. The following conception will give an idea of the defacing force of the blow: Suppose the rail joint were under a steam hammer the head of which weighed 1000 pounds, and that the hammer head had a velocity of 3 feet per second at the moment of impact. If the hammer so actuated were to deal the rail joint a series of such blows, it is easy to see that the strongest construction could not long endure.

If the rail joint was rigid the hammer would rebound with practically the same velocity. It does not require an engineer to see that he may expect a precisely similar

effect in case of a heavily loaded car wheel, under such conditions as have been outlined in the preceding paragraphs; and that the facts bear out the theory every railroad man knows.

To minimize this pounding action of car wheels over rail joints we must arrange the weights that rest directly upon the car wheels, or are rigidly coupled thereto, in such a way that when the wheels are lifted, due to meeting any obstruction, the center of gravity of the rigid system shall be raised the least possible amount. To put these directions in more practical diction, we must have less dead weight on the car axle.

The gearless motor, which is largely a future development commercially, involves this problem to a serious extent, but inasmuch as present street railway traction is confined entirely to single reduction motors, the greatest interest attaches to their methods of suspension.

It is evident that there must be a rigid connection of some kind between the motor and the car axle, for otherwise the gears will not keep in mesh. The distance between the centers of the gear and pinion must be a constant quantity. The simplest and most used device is to cast an axle bearing directly on the upper or lower half of the motor casing, thus rigidly con-

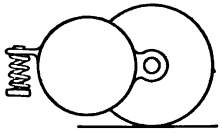

Fig. 124.—Simple Spring Suspension.

necting the motor with the car axle. Such a case is illustrated in diagram in Fig. 124.

The motor should be so designed that its center of gravity should be as far from the car axle as possible,

for this will carry the center of gravity of the entire system in the same direction. The diagrams in Figs. 125 and 126 illustrate this principle. It is obvious

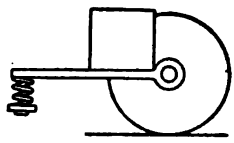

Fig. 125.

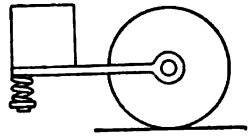

Fig. 126.

that in Fig. 125 the center of gravity of the system is raised higher at the instant when an obstruction is met than in the case of Fig. 126, and as the blow on the rail joint is practically proportional to this lift, a gain of a mere fraction of an inch may represent hundreds of pounds in the reduction of the impact blow; therefore when considering suspensions of this type, the buyer of motors should look favorably on those which have axle bearing brackets at considerable distance from the armature shaft; always providing that the wheel base of his trucks will permit him to use such a motor.

The weight of the wheels themselves, of the axle bearings, and of the gear is inevitable, but much can be done to mitigate the weight of the motor. If we can suspend the motor from the truck exactly at its center of gravity, we shall have a system in which

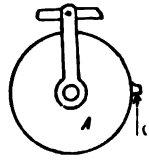

Fig. 127.

there is no dead weight on the axle, provided that the motor is not doing any work—a condition to be discussed presently. Consulting Fig. 127, this principle

may be more clearly understood. If we have a mass, A, supported at its center of gravity, and an impact, C, drives that portion of the mass upward as shown, the center of gravity of the mass will not be raised at all. The body will simply turn upon its center of gravity as an axis. Inertia has to be overcome to do even this, but the force which is expended is not nearly so great as in the case where the center of gravity of the system is lifted.

This condition has been approximately realized by two well-known suspensions, used by the General Electric and Westinghouse companies respectively. These are known as side-bar suspensions.

In the General Electric adaptation of this principle, which is shown in diagram in Fig. 128, two bars of

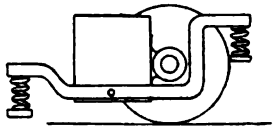

Fig. 128.—General Electric Side-Bar Suspension Principle.

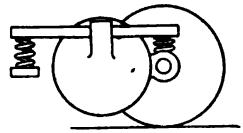

Fig. 129.—Westinghouse Side-Bar Suspension Principle.

suitable shape pass on either side of the motor, and are suspended by their ends to the truck frame. The bars pass downward and below the center of gravity, and are attached to the motor by cylindrical lugs, and are supported as shown. The result of this is to actually lower the center of gravity of the motor when the wheels are suddenly raised. The condition is one of unstable equilibrium, the motor being balanced, as it were, on the lugs. This should be a most excellent arrangement, for the weight of the motor tends to assist the car wheels to rise instead of impeding them. Nevertheless, to move the mass of the motor in any way requires that inertia be overcome.

The Westinghouse adaptation of side-bar suspension (see Fig. 129) is somewhat different, the motor being suspended from above its center of gravity rather than below it. The equilibrium of the motor on its suspension is a stable one and requires a certain force to displace it, which force is expended on it by the car wheels when they are driven upward. The side bars pass through straps, which are cast in the side of the motor frame, as shown in the figure, and the point of support is very near the center of gravity, so that when the car wheels strike an obstruction, the latter point is only very slightly raised.

Following out this reasoning it would appear that supporting the entire system by its center of gravity would result in an easier riding suspension than any heretofore constructed on this principle. Such an arrangement is shown in Fig. 130, and it will be seen at

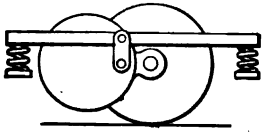

Fig. 130.—A New Method of Suspension.

once that the weight of the motor counterbalances the weight of the car wheel and axle, and should make it very much easier for an obstruction to force the car wheels upward, resulting in a largely reduced blow on the rail joints. This arrangement throws the weight of the motor on the truck frame, from whence it is transferred to the bearings through the medium of springs, and hence, while it does not relieve the axle from any weight, in the end, very much reduces the rigid riding weight. From a practical point of view this suspension seems to be very feasible, yet no one

has attempted anything of the kind so far as the writer is aware.

The adaptation of the side-bar suspension of the Westinghouse motor has created considerable criticism among engineers, because at first sight it appears analogous to the case of lifting one's self over the fence by the boot straps. One end of each side bar is supported in lugs, cast on to the motor frame itself, and projecting beyond the far axle. About half of the weight of the motor appears to ride on the axle, and, indeed, this is the case as long as the motor rides over a smooth roadbed. If, however, the wheels meet an obstruction and are driven upward, the motor tends to turn about its center of gravity rather than to be lifted. This suspension is shown in Fig. 129.

A modification of this suspension, known as the cradle suspension, has been used in some cases. This consists in simply bending the side bars around to form a U, and suspending from a point, as shown in Fig. 131. It is really a combined side-bar and nose

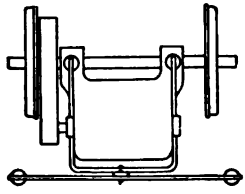

Fig. 131.—Cradle Suspension.

suspension, the latter being a cant name for the ordinary method for suspending railway motors by a spring-supported nose or lug cast on to the motor frame, as shown in Fig. 124. This latter suspension has been slightly modified into what is known as the yoke suspension, in which a crossbar is rigidly bolted on to seats cast on the motor casing, and the ends of

these bars are spring-supported on the truck frame. A yoke suspension, as used by the General Electric Company, is shown in Fig. 132.

A new suspension was placed upon the market by the Walker Company of Cleveland, Ohio, and it in-

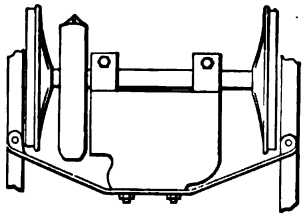

Fig. 132.—Yoke Suspension.

volved several features which certainly appear to make it a valuable method, and practically it has seemed to bear out the claims. The gears are kept in mesh by two space bars, which rigidly connect the axle and armature bearings, but allow the mass of the motor to move freely up and down. These space bars are cast on the ends of a split tube or sleeve which surrounds the car axle, and the motor itself is free to turn in the bearings provided for that purpose in the ends of the space bars. The result of this is that

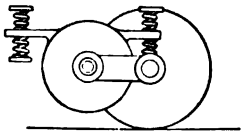

Fig. 133.—Walker Suspension.

when the car wheels are suddenly forced upward the center of gravity is neither raised nor does the motor revolve upon it, but remains perfectly stationary, the

force of the upwardly driven axle being gently arrested by springs which connect with lugs cast on the top of the motor casing. The principle of this suspension is depicted in Fig. 133. Under the pressure of legal discussion against it the Walker Company was forced to abandon this device and suspend the free end of the motor to a rigid yoke, as shown in Fig. 134. It is a question whether this change was

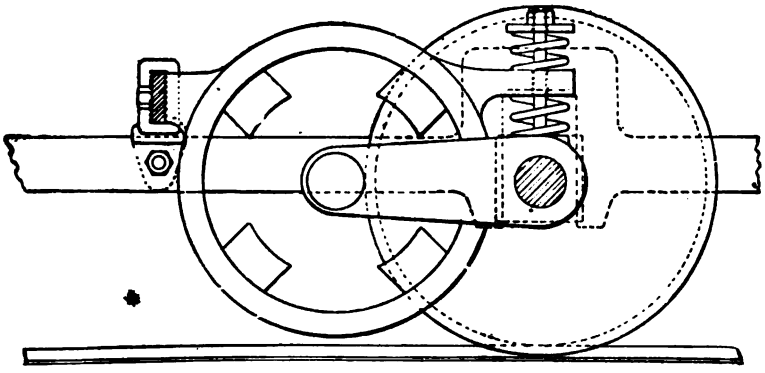

Fig. 134.—Latest Walker Suspension.

not a real advantage, for the suspension of Fig. 133 gave the motor a great deal of freedom of motion and rendered it much more likely to collide with objects in the road bed.

There are, however, other considerations in a suspension than those of the riding of the motor as a dead weight. The motor is the driving factor, and when its armature is driven in one direction, its casing tends to be driven in the opposite direction, and this tendency to turn is resisted by the suspension.

For instance, considering the simple nose suspension, as shown in Fig. 124, if the truck be driven to the left, the motor will tend to climb up the gear on

the car axle and raise its mass as a whole; indeed, unless prevented in some substantial way, the motor is likely to strike against the car floor. This tendency to rise should be resisted by a spring on the upper side of the lug or nose, or the result will be that the jerks and strains of the motor will be rigidly directed on the truck frame and the gears. If the car be moved in the reverse direction, that is, to the right, the motor tends to climb downward on the gear, adding to the pressure on both car axle and suspension crossbar, but the suspension springs provided for supporting the motor should also absorb such jars as may be communicated in this way. Nevertheless, when driven in this direction, the motor rides more rigidly than when driven in the other, for the suspension springs are more strained and less elastic.

We have, therefore, two principal desiderata in motor suspension. The first and most important is that a sudden upward thrust on the car wheels shall move as little weight as possible, either by directly lifting its center of gravity or causing a rotation about that point, for even the latter action requires that inertia be overcome. The second requirement is that the tendency of the motor case to revolve should be stayed by spring cushions, for if it is rigidly arrested, the gears will suffer and the motor will ride with great vibration. In all moving vehicles the spring suspension should be as close to the point of shock as possible, in order that the jar transmitted to the vehicle be absorbed without moving any large mass.

One of the most beautiful practical illustrations of this principle is the pneumatic tire. Vehicles thus equipped can ride with comparative ease over the roughest roadbeds, simply because the minute vibrations are all absorbed before they can be transmitted

to the axle of the vehicle. Pneumatic tires, of course, cannot be employed on electric railway cars, and we must approach the condition as nearly as possible by making the weight of the member which receives the vibrations rigidly, namely, the car axle, and all parts of the equipment that ride rigidly thereon, a minimum.

CHAPTER VIII.

BEARINGS AND GEARS.

THE bearings in a street railway motor are very important parts in its construction. In modern motors they consist for the most part of cylindrical shells which are lined with some good anti-friction metal. These shells are sometimes of one piece and are slipped over the end of the shaft, and sometimes they are in halves and doweled together. Axle bearings, of necessity, are always in halves, for it is obviously out of the question to press off a car wheel every time it is desired to install a motor.

Some of the early motors, notably the W. P., and some of the Curtis "A" motors, used brass shells. These were of metal, about ⅛ of an inch thick, in the case of armature bearings, and were allowed to wear to 1-16 of an inch before they were thrown away. They were very satisfactory so far as running qualities were concerned, but they are expensive to maintain, both on account of the relatively expensive metal which is used and the fact that each bearing shell required to be machined before it could be used; therefore babbitt bearings have come now into almost universal use.

In the selection of a babbitt metal it is very common for street railway men to go by price. They know that a six-cent metal is next to worthless, and they argue, or rather act upon the supposition, at least, that if eighteen, twenty, or twenty-five cents a pound is paid they are sure of getting something that is satisfactory.

It is one of the tricks of the engineering trade to make up a metal which will form a moderately good bearing, give it an imposing name, and sell it at a high figure; and a few words as to the nature of anti-friction metals may not be out of place.

The substance which is largely used as a filling in the composition of cheap metals is lead. This alone is, of course, too soft to stand mechanical stresses, and a bearing babbitted with a metal containing too much lead will fail by the metal squeezing out at the ends after the fashion of putty, and, it may be added, this happens very soon after the bearing has been put into service. A common test, therefore, has been to take a stick of the bearing metal and see if it will make a mark on white paper. The assumption drawn, if such be the case, is that the metal contains too much lead to be suitable. In the opinion of the writer, any bearing metal containing lead is unfit for railway use.

The United States Navy Department made a series of exhaustive tests on the various bearing metals in the market. These tests were strictly comparative, genuine babbitt being taken as the standard, and it was found that no metal equaled it in either wearing or anti-friction properties. Many of these patent compounds were assayed and it was found that the all-around excellence of the bearing metal was in almost direct ratio with the proportion of tin that it contained. Genuine babbitt is almost pure tin, with just enough copper to make it tenacious and just enough antimony to make it flow nicely, and stood at the head of the list. Such a mixture is worth in the neighborhood of twenty-five cents a pound and varies according to the market, and all of the patent metals which were assayed by the Government were found to be of less

value, figuring from the prevailing prices of the respective metals they contained. This seems to show that anybody who pays over twenty-five cents a pound for bearing metal of any kind is paying for royalty and reputation and not for car mileage. Anti-friction metals, like genuine babbitt and others of lower grade, should be melted very carefully. If the heat be applied too rapidly, some of the metal will oxidize and be skimmed off as dross, thus altering the proportion of the mixture. The metal so lost generally comprises the hardening medium and renders the resulting alloy much inferior; thus it is possible to make a specious test to the disadvantage of a really good bearing metal. Just before pouring a bearing, the metal should be thoroughly stirred, for the heavier components tend to exist in the greatest quantity in the bottom of the mass, and unless this precaution is taken the bearing will not be made of the true mixture.

In casting babbitt bearings, it is very important that the various lots of metal be kept separate. Each batch of shells should be marked by some private mark, showing the lot from which they were cast, and when those shells are returned to be rebabbitted, the old babbitt must be kept in a lot by itself and not mixed with new, even though it is supposed to be of the same quality. The reason for this is that the babbitt may have been carelessly heated and poured, and its quality materially altered as before described, in which case mixing it with new babbitt will seriously deteriorate the value of the entire melting.

If the old babbitt is to be used again it should be melted and used by itself. It is well to reject the babbitt from bearings which have prematurely ground out, on the supposition that the metal was overheated or not properly stirred in the pouring. The addition

of one worn-out shell of burnt babbitt might seriously injure 50 pounds of good metal. It is obviously experimental to mix different grades or makes of anti-friction metal, and it is very probable that the resulting mixture will be inferior in quality to either of its components.

There are two methods which are much used to make babbitt metal bearings. The first is to cast them carefully on a mandrel of the proper size, and the second is to cast them with a mandrel that is a few sixty-fourths of an inch smaller and ream the bearing to size. If carefully done the latter is the preferable method, but too often the work of reaming is so carelessly performed that it would be better to cast the bearing to size in the first place. The reaming process has the advantage of exposing a clear metal surface free from oxidation and supposedly better adapted for friction, but the difference is slight and the real value of reaming consists in the high mechanical accuracy of fit. Large hand reamers are very expensive, and frequently the lathe is called into service for this purpose. In such a case the finishing chip should be very light, the carriage should be set to a fine feed and the tool should be so shaped that it will take off a chip after the manner of a hand scraper, thus leaving a smooth polished surface and one not filled with tool marks.

Reamed bearings and possibly hand-scraped bearings are advisable for armatures where the speed is high, but unless the work is very carefully done it is labor wasted, for the plain mandrel-cast bearing will prove superior to a poorly machined one.

The oil grooves should be chipped in after the bearing is reamed, as they are liable to interfere with the action of the cutting tools. Usually all that is necessary in the line of oil grooves are two marks cut with

a U-nosed cold chisel, crossing each other diagonally, the grease orifices being at their intersection.

If the bearing is to be cast and not reamed, the mandrel may be made out of a piece of shaft, of the same size as the shaft on which the bearing is to finally operate. The mandrel may then be smoked in a torch flame so that a thin layer of soot will give the bearing clearance, and prevent the mandrel from sticking. The better way, however, is to use a mandrel 1-64 of an inch large, and give it a light coat of oil, just sufficient to make it greasy, but not enough so that the melted metal will sputter and bubble when poured upon it. A common procedure is to make two collars, which may be secured to the mandrel by screws, as shown in Fig. 135. These serve to center the bearing upon the mandrel and hold it in position while the metal is being poured. The bearing shells themselves should be exceptionally free from grease and oil, so that the babbitt will stick to them. For this purpose they may be washed in a strong solution of ordinary washing fluid or potash, which will effectually cut the grease and remove it. When thoroughly dry and cleaned they are ready to be babbitted.

The shells and the mandrel should be slightly warmed, almost hot enough to be inconvenient to handle, and the grease ducts and the edges of the mould should be stopped by wads of clay. The bearings should then be poured in a vertical position, preferably through a hole in the collar, though it is common to pour them on the sides through one of the grease ducts. The latter method has the disadvantage that any imperfection in the pouring appears on the bearing itself, while, with vertical pouring, imperfections, if there be any, are more likely to occur at the ends where they will not do any particular harm. As soon as the

metal is set, the mandrel should be cooled as rapidly as possible by taking off the collars and dipping the end in cold water, still allowing the bearing to remain hot, and presently it can be easily driven out with a rawhide mallet. Care should be taken that the ends of the mandrel projecting from the bearing are smaller

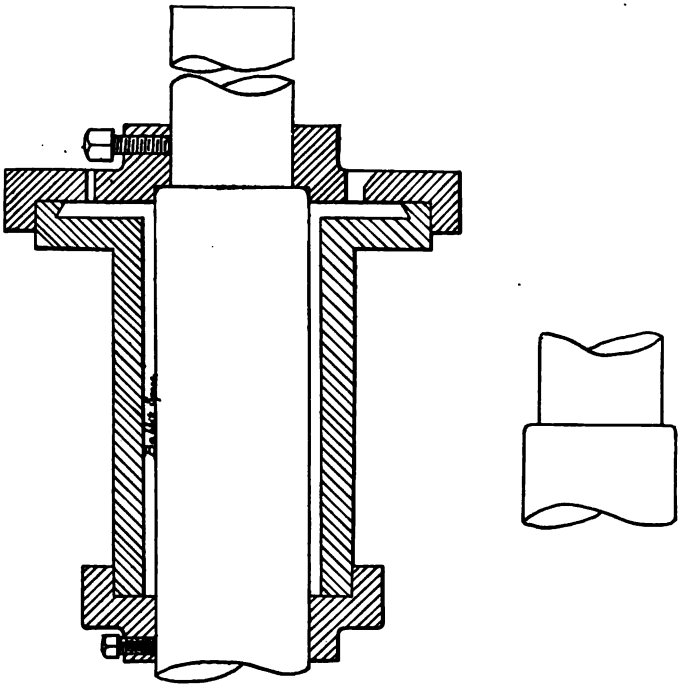

Fig. 135.—Babbitt Mandrel and Collars.

than the bearing itself, and that any sharp edges where the size changes be carefully rounded, for if the mandrel is not driven straight out, such edges are liable to damage the finished surfaces. In casting these cylindrical bearings a very slight taper will be of assistance in removing the mandrel. The difference in diameter in the bearing ends should not exceed 1-64 of

an inch, and it is best to get along without a taper, if possible, unless the bearing is to be subsequently reamed.

The metal should be heated just enough to run freely. The rule should be that the metal be just hot enough so that when it is poured it begins to solidify at the bottom just after the pouring is finished. If any cooler, irregularities in the pouring will fill the bearing full of notches, and if any hotter, the composition of the metal will be altered, invariably to its detriment. To avoid oxidation, the babbitt should not be kept melted any longer than absolutely necessary.

Another device for babbitting boxes which is very practical has been recommended by Mr. B. F. Fells. The parts of his device are shown in Fig. 136, and the

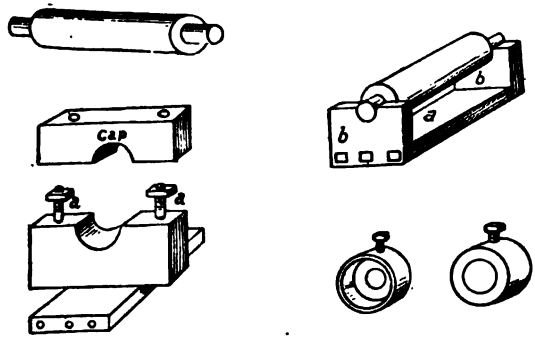

Fig. 136.—Parts of Babbitt Mould.

assembled apparatus appears in Fig. 137. In this device the bearing shell is held about the mandrel by means of a wooden clamp and the mandrel rests in two end bearings. In Fig. 138 is shown a furnace suggested by Mr. Fells to be used in melting the old metal out of worn boxes. The feature of this device is that the metal is drawn off from the bottom, thus avoiding

scum. It may be added that such a furnace is very suitable for melting new babbitt also.

The same precautions that apply in casting babbitt metal are to be observed in cast-brass bearings. Brass can be so badly burned that it can be broken with the

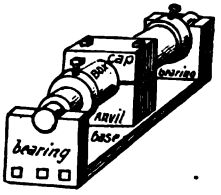

Fig. 137.—Complete Babbitt Mould.

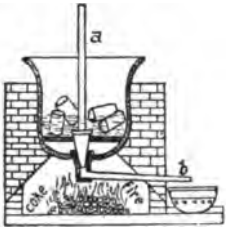

Fig. 138.—Babbitt Furnace.

fingers, giving a black cakey fracture, and yet such burned brass can be brightly polished and externally will appear thoroughly suitable. Therefore, in selecting brass for casting bearings, old bearing brass may be used, provided that it has not been remelted too many times and its fracture appears satisfactory. But, as is the case with babbitt, it is better to keep track of the lots of metal, and after they have been used four or five times, to reject them for bearings. Old babbitt of course is valuable only as junk, but old brass can be advantageously used for many small castings employed in railway work.

Split bearings are commonly cast on a half mandrel, placed on a flat surface and covered by the bearing shell. Such a mandrel is quite expensive to make, and its use may be avoided by making up a half shell with a highly infusible lining, such as very hard brass, and machining it to exact dimensions. This prepared shell may be used in connection with the shell to be babbitted with the two collars, and the ordinary man-

drel, as described in the method of pouring cylindrical bearings. The edges of this dummy shell should be oiled slightly to prevent the babbitt from sticking.

In babbitting brass bearing shells, which are sometimes used on axles and occasionally on armatures, the surface to which the babbitt has to adhere should be tinned with rosin or soldering acid. This adhesion is not possible in the case of cast-iron shells, and therefore the latter should be thoroughly cleansed, as has been described, and liberally provided with grip holes drilled in diverse directions. A well-babbitted bearing, when dropped from a height of 6 inches on to the bench, will sound like a solid piece of metal, and if the work be poorly done such a fall will produce a brief buzzing sound like that of a cracked bell.

Railway motor bearings are almost identical in shape as manufactured at present, but there is one point that deserves mention before leaving the subject, and that is the interchangeability of the bearings of a motor. It is obvious that the pinion bearing has much more strain imposed upon it than the commutator bearing, and good design dictates that it should be longer, but, on the other hand, bearings that are interchangeable are a great convenience, provided this interchangeability is not secured at the expense of mechanical design, that is, the pinion bearing is made too short and the commutator bearing too long. It is plain, however, that for this to be, the commutator bearings must be longer than is absolutely necessary, and this will often make the motor so long across the axle that it interferes with the brake rods. Indeed, the length of the motor bearings is frequently limited by the space to spare, and in several cases, notably that of the W. P. 50 motor, in which the commutator bearing is scarcely longer than its diameter, the bearings have

been sacrificed. Therefore, it is usually better practice when space is so limited to make the pinion bearing the larger.

The most common method of connecting railway motors to the car axle is by means of spur gearing. The original motor of Sprague used the single-reduction gearing which is so widely adopted to-day, but owing to the inability of designers at that time to produce motors of sufficiently low speed and powerful torque, single-reduction gearing was abandoned for double-reduction methods, which were in vogue until 1891. Then it was that single-reduction motors made their advent, and their success was so emphatic that at least two well-known companies attempted to go still further and produce a gearless motor. In this they were not successful, for the motor started too slowly and was too expensive to compete in the market, and the advantages to be obtained, of avoiding gears, were not a sufficient inducement to pay the high price. The first gears of railway motors were entirely unhoused, and they so rapidly ground away that it was not at all uncommon to renew them after a run of three or four thousand miles.

To the Westinghouse Company is undoubtedly due the credit of introducing gear cases, which were used on their No. 1, the first bipolar form that they placed on the market.

At this time running gears became such a large figure that the single-reduction types were eagerly patronized on account of maintenance, the elimination of noise, and the reduction of wear and tear. With the single-reduction motors came the device of housing the gears with a metal casing and running them in heavy grease. This practically eliminated the noise

and brought the mileage of the gears from 4000 up to 25,000 miles. The slowest speed motors necessary for double reduction were, however, much heavier than their high speed predecessors, and even to-day managers frequently express a preference for double-reduction motors over the early single-reduction type.

Cast-steel casings and modern design have, however, so greatly reduced the weight of single-reduction motors that there is no question that even with an equally well-designed double reduction motor, the gear item would still be a prohibitive disadvantage. The common ratio of reduction between gear and pinion varies between 3 and 5 to 1. In the larger motors the reduction ratios are lower; but in order to increase the distance between armature shaft and car axle, pinions and gears are both made quite large.

The standard American practice is now the single system of spur gears, even though there have been numerous attempts with all other methods of transmitting power from motor to car axle. A unique method was that of Eickemeyer, in which a connecting rod was used. This rod joined two crank pins on the car wheels and the motor which was set between them was connected by means of a crank disk and pin to the middle of the parallel ones and therefore at the same speed as the car wheels. This device is shown in Fig. 139. The space between the wheels was ingeniously utilized to contain a very powerful motor, and as far as the motor problem was concerned, the solution was excellent for the time, and had it been kept in step with modern improvements would doubtless still be a competitor. The practical difficulty which caused the downfall of this method was the fact that the connecting rod ground out in spite of every precaution that could be taken. So persistent was this action

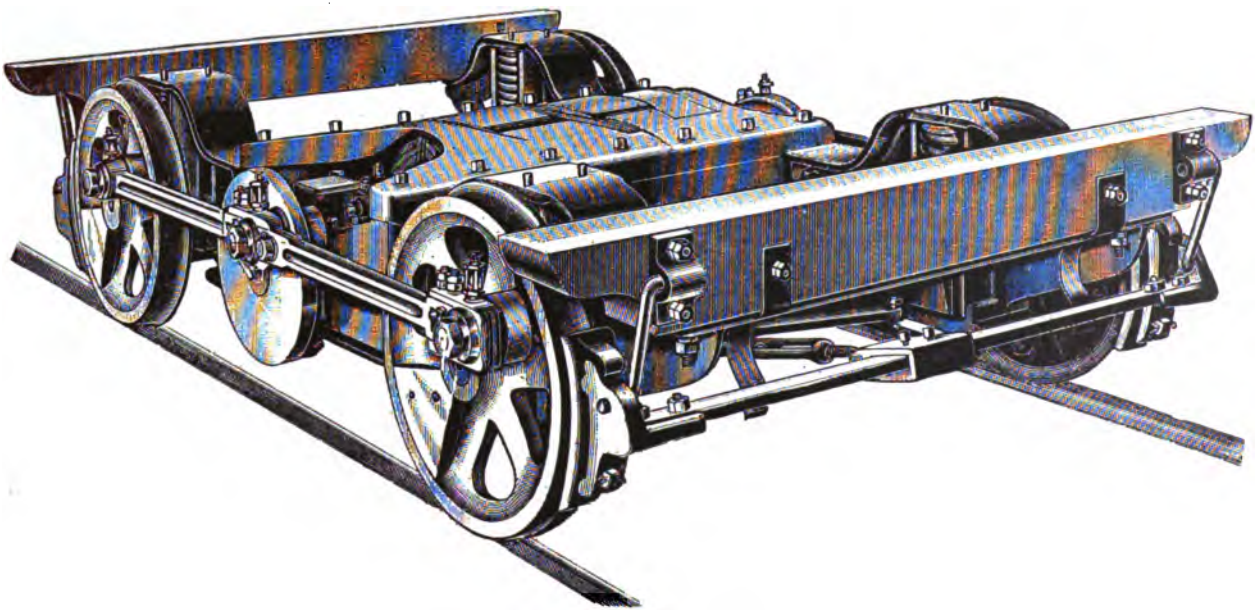

Fig. 139.—Eickemeyer Gearing.

that it seemed almost mysterious, but the fact still remained that a new bearing on the Eickemeyer plan would become so loose in a single day that it needed attention. This fact is of interest because it effectually demonstrated that systems of traction for street railway work, in which pistons, sliding surfaces, or connecting rods are employed, will encounter this difficulty, which engineering skill has so far failed to eliminate.

Another device for connecting the car wheel to the motor axle is that of Sperry, in which the two axles were connected by beveled gears to a single large motor suspended between them. The principle is shown in Fig. 140. With this device it is necessary to have

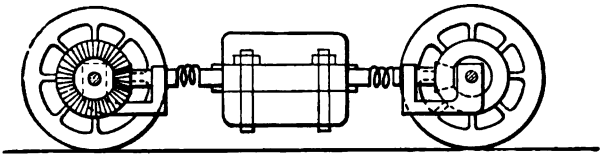

Fig. 140.—Principle of Sperry Gearing.

flexible connections between the motor and the car axle, and these are indicated by the springs S S in the figure. The details of this device are shown in Figs. 141 and 142. The beveled pinion was made fast to the shaft, which carried at its extremity the toothed wheel which meshed internally with the larger toothed annulus, which it drove by simple pressure and not by any gearing principle. The teeth were so shaped and of such dimensions that one wheel was certain to engage the other, no matter in what position the inner wheel might be. The outer rim or annulus was supported in a shell with blocks of rubber, indicated by the shaded circles in Fig. 142, and a twist in either

direction would compress these blocks. It is plain that this device permitted a certain amount of lack of alignment between the two sections of shaft to which

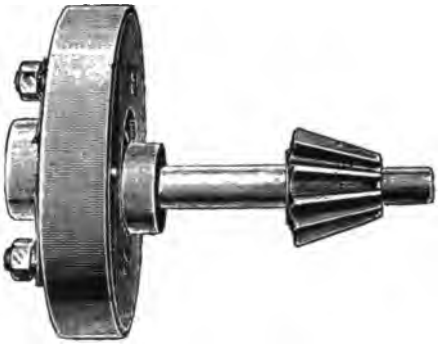

Fig. 141.—Sperry Flexible Connection.

it was connected, and further the coupling was elastic and sudden strain could not be transmitted from motor to axle or vice versa. It was claimed for this device that a single large motor would replace the double

Fig. 142.—Principle of Sperry Flexible Connection.

equipment commonly employed, and this motor would therefore be of higher efficiency, more durable, and generally superior. Further than that, it was held that with the double coupling, two car wheels were driving wheels and that traction was therefore in-

creased. The single motor, however, sacrificed the great advantage of series parallel control.

Still another device for driving motors is by means of a system of worm gears. The chief objection is the inefficiency of worm gearing, but there are many advantages in its favor. In the first place, the motor itself need not be rigidly set upon the car axle, but can be spring-suspended from the car frame. A vertical motion of the motor as a whole simply resulted in moving the motor backward or forward, as the case might be. A second advantage which obtains in a worm gear is that it is possible to attain a very great reduction, thereby permitting the use of a very high speed motor. This reduces the weight of the equipment as a whole, and the cost of maintenance is much less on small motors than on large ones. An advantage obtains in the fact that the worm gear is not a reversible combination, and hence the shutting off of the motor constitutes a brake, and once at rest the wheels are locked. Indeed, it becomes necessary to shut off current gradually to avoid too abrupt a stop. A small mechanical brake, which can be applied to the shaft of the motor and which will require very little power, will act as an emergency brake, and in this way the speed of the car can be accurately controlled at all times. A disadvantage in this method is the necessity of releasing the coupling of a disabled motor from the car axle in order to enable the good motor to operate the car, and if both motors are disabled, both must be uncoupled before the car can be towed.

It is very easy to effectually house worm gearing, and worm gearing is notably noiseless.

It seems to the writer that the possibilities of this method of traction have not been fully developed and that, if modern methods are employed in perfecting

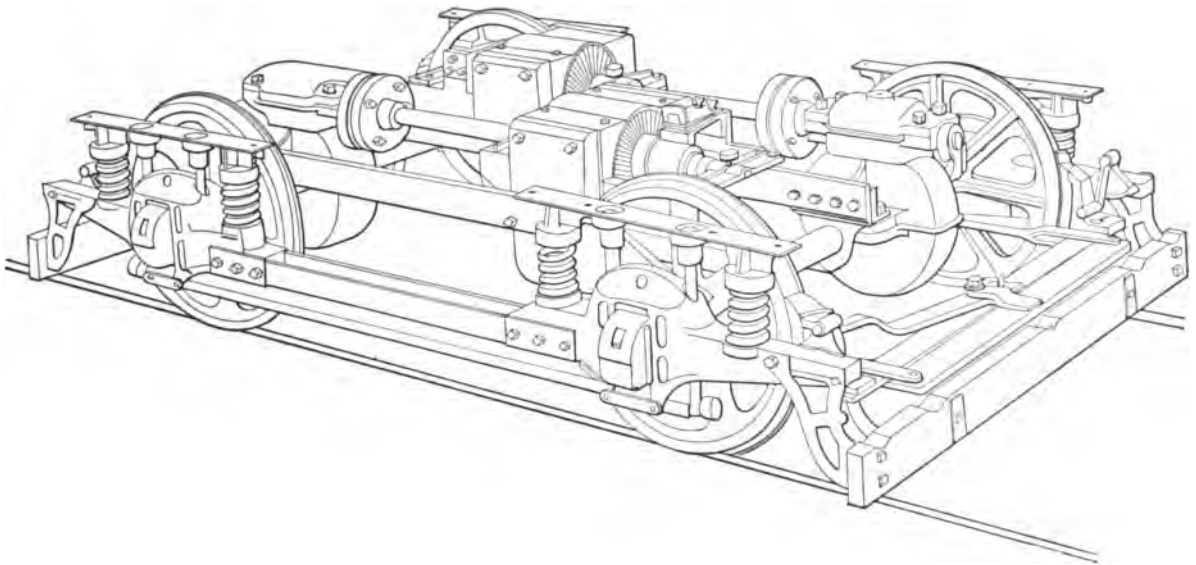

Fig. 143.—Worm Gear System.

a worm gear, highly satisfactory results will be obtained. In Fig. 143 is shown the worm gear of Greenwood Batley construction on the plan of the late Anthony Reckensaun. The two little motors shown in the figure are of 10 h. p. each.

CHAPTER IX.

LUBRICATION.

THE lubricant of street-car motor bearings is preferably grease. It is not a clean lubricant, but it is what might be called a dust-tight one, for dust and flying particles will find it much harder to work into and grind out a bearing which is lubricated by grease than one which is lubricated by oil. Therefore, grease is almost universally used on street railway motors. Oil is sometimes advisable on interurban and elevated roads, where the journals are very heavy and where liability of trouble from dust and grit is very much reduced.

Another advantage of grease is that its viscosity very much reduces the chances of its being thrown out of the bearings and over the windings. In elevated railway work, where oil is superior for mechanical reasons, this trouble of flying lubricant is largely experienced and has proven a substantial practical difficulty.

There are more different lubricating compounds than there are anti-friction metals, and that is saying a great deal. It seems to the writer that almost every conceivable substance has been tried. Powdered lead, lime, rosin, salt, soapstone, caoutchouc, sulphur, beeswax, carbonate of soda, gutta percha, ivory dust, and asbestos are only a few of the many materials which no one would suspect could be beneficially used in any lubricant, but which have, nevertheless, been employed as components in the preparation of lubricating compounds.

It is not possible to lay down any rigid rule for lubricants. The temperature and load conditions have much to do in determining it, and these are liable to vary. It may be better to use a lighter grease in winter than in summer; in fact, this is often done, and practical experiment is the best guide. Greases containing graphite or soapstone or similar ingredients are better suited for gears and parts where rubbing is not continuous. Animal oils or tallows are liable to contain acids, which should be neutralized with soda or caustic potash, according to some approved formula. Vegetable oils are liable to be of a drying variety, that is, they will thicken and gum on exposure to atmosphere, and they should not be used in a lubricating compound to such an extent that this property proves objectionable. A vegetable oil will carbonize on a bearing at a relatively low temperature. Lubricating compounds known to contain a percentage of vegetable oils should be tested severely before being approved. A carbonized vegetable oil in a bearing produces a surface of about the same texture as a sawed piece of carbon, and it enormously inereases the friction both by its roughening and its filling up the clearance so that the axle binds.

Axle grease, for the most part, consists of animal tallows, the acids of which have been neutralized with soda.

A formula for common railway grease, suitable for axle boxes and bearings, is as follows: Melt 200 pounds of tallow and stir in 150 pounds of palm oil; boil, and then allow to cool until about 90° F. Stir continuously. Then strain it into a solution consisting of 60 pounds of soda dissolved in 3 gallons of water, stirring the two together.

Another axle grease, suited for summer use, is as

follows: Tallow 450 pounds, palm oil 250 pounds, sperm oil 27 pounds, crystallized soda 108 pounds, water 1220 pounds. The lubricant should be heated and melted in one vessel to about 180°, and the water and soda heated in another till just below boiling point. They should then be run together and stirred till cold. The slower the cooling process the harder the product. For winter use 75 pounds less tallow and 8 pounds more sperm oil, 6 pounds more soda and 10 pounds more water. In those greases where soda and other basic alkalies are so largely used, they not only neutralize the acids in the fats, but they unite with a considerable percentage of the grease, forming soft soap, which frequently forms a principal component of axle grease.

Another grease suitable for gears is: graphite one part, lard four parts, to which a very small quantity of camphor has been added.

There are many good axle greases now offered on the market, and one or two of them are of such admitted excellence that they have become standard.

The practice which is much approved and largely used is to provide a combination lubricant of oil and grease, grease cups being supplied above the bearing and oil wells with felt wick wipers below. The grease is hard and acts as a reserve. An overheated bearing will melt it, thereby providing additional lubrication.

In inspecting railway motors particular care should be taken, if grease is the lubricant, to prevent it from entering the motors. Ordinary ducts which would carry off oil or light lubricants may be easily bridged by grease. Grease and oil are insulators in themselves, but have a rotting, disintegrating effect on insulation which is very destructive.

CHAPTER X.

GENERAL DATA AND DIMENSIONS.

THE preceding chapters, while descriptive of modern practice in electric railway motors, have to a certain extent reviewed development, and compared the most modern development with some of the much used and older forms. It is interesting to note which way general practice has tended.

With regard to motor cases there is no question but that the preferred form is the iron-clad four-pole machine, all the poles being salient. The consequent-pole machine, unless very carefully designed, is certain to produce sparking troubles at the commutator, due to the fact that the consequent poles do not afford the same intensity of field at their tips as do the salient ones. Moreover, a consequent-pole machine is essentially long in its vertical dimensions. It does not divide conveniently excepting on a line parallel with its field windings. Abroad, a diagonal division has been tried, thus turning the motor in such a position that its shortest dimension is a vertical one. This certainly seems to be an improvement over American practice in consequent-pole street railway motors, but has only been used by the home companies in one case, that of the Sperry Electric Railway Company, formerly of Cleveland, Ohio. The four-pole salient machine was first introduced by the Westinghouse Company, and is now universally used in American practice.

The bearings on railway motors are receiving much

more attention by modern designers. They have begun to appreciate that the greatest wear and tear come upon the pinion bearing, and that it desirable to make this as long and substantial as possible. Eight inches is not an uncommon length on modern 30-h. p. sizes.

While the iron-clad housing is a necessity in street railway work, it unquestionably confines the heat and reduces the permissible output of the motor, and on heavy traction work over private rights-of-way or elevated railway work, where the mud and dust conditions are not severe, modern practice leaves the motor case open as much as possible. The practice of having all the casings of street railway motors closed by hinged bolts is a desirable feature and is being largely adopted.

The most used method of opening street railway motors is now to swing the lower half downward, and provide means by which the armature may be retained in either half at pleasure. This method was first introduced by the Westinghouse Company. The Walker Company quickly followed suit with its first machine, and later the General Electric Company adopted the practice in the G. E. 52 machine. There are still special cases where it is preferable to dismount the motor from above, and some of the later motors are built to fit this requirement. Fig. 144 illustrates this system of inspection.

The pole pieces on the larger sizes of modern motors are now being constructed of laminated plates. These plates are bolted together in a bunch and then drilled and countersunk with holes parallel to the laminæ and secured to the casing by long bolts. The object of this has been to increase the efficiency of the machine. Within the past year strenuous efforts have been made by modern designers to increase the effi-

ciency of the railway motor. This has been a difficult task, for in spite of all efforts it has stuck very persistently at about 85 per cent. Some of the most recent results, however, are surprisingly good. The efficiency has been brought up in some cases, so the makers allege, as high as 92 per cent., a figure closely approaching generator efficiency.

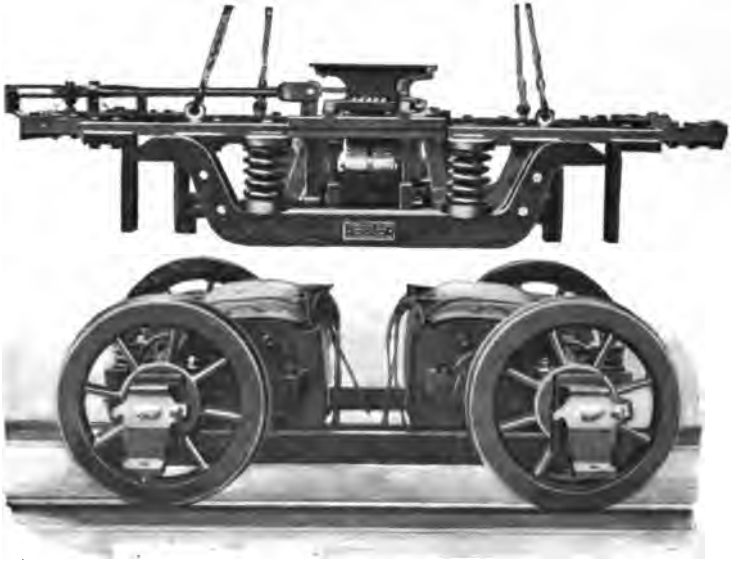

Fig. 144.—Method of Exposing Motors for Inspection by Removing Upper Part of Truck.

The preferred armature winding is now on the straight-out plan. The reduction of dead wire on the armature circuit, combined with the ease of inserting the coils, is too great an advantage to be overlooked. The chief objection that has been urged against the straight-out winding is that it produces an excessively long armature, but the fact that it is generally adopted in railway practice has effectively demonstrated that

the objection is not a valid one, for in no case of dynamo or motor design is a short armature more desirable than in a street railway motor.

It remains for practice to show if the new Westinghouse combination of spiral straight-out methods will prove superior to any yet used.

The toothed armature undoubtedly owes its present popularity largely to the street railway motor. Its magnetic efficiency and its ability to withstand severe service were so well demonstrated in this field that it has been widely adopted elsewhere. Modern practice in street railway armatures seems to tend to reducing the armature diameter and the number of slots and increasing the number of conductors per slot. A most marked illustration of this policy appears in the G. E. 800 and G. E. 52 motors. The first motor has 105 slots and 6 wires per slot. The second, which is the more modern type, has 29 slots and 24 wires per slot. Railway motors have to be repaired so frequently that this is a great advantage, as it adds to the ease of winding; besides, it makes the teeth on the armature much broader and enables them to withstand the severe abuse which they would receive if the bearings were neglected and the armature allowed to strike against the pole pieces.

The universal winding used for street railway motors is the series or wave winding, employing two brushes on the quarter, although, if desirable, four brushes could be used for the sake of greater conductivity. By this winding the number of brushes is reduced, their position is conveniently arranged underneath the lid over the commutator, the speed of the motor is one-half that which would obtain with a parallel winding with the same number of conductors, and the two-circuit winding is not affected by the un-

balancing which might occur by the decentralization of the armature. All of these are very important advantages in railway motor design.

The popular gearing is the single-reduction spur gear, although great results are predicted for the gearless motor in heavy sizes. It may also be added that the worm gear has never received a fair trial in this country, and that it possesses a great many advantages which by no means are insignificant. The worm gear permits the use of a motor of high speed and efficiency, which incidentally involves very much reduced rate, and further the motor connected by worm gearing need not be mounted rigidly on the axle, but can be completely spring-suspended at a long distance therefrom. Still another advantage obtains in the fact that a motor so geared becomes an effective brake on the wheels unless supplied with current. The wheels cannot turn the motor, for the worm gear is not a reversible combination unless the pitch of the worm is very high. The fact that many of the old Sprague double-reduction motors are now being used on many street railways and are preferred by many managers to some of the early single-reduction types, such as the W. P. 50 and Westinghouse No. 3, gives ample notice that a light motor would be well received, even at the expense of a lower efficiency in the gearing. It is further to be added that the worm gear is noiseless.

In the days of exposed gears, sprung shafts were of such frequent occurrence that considerable attention has been devoted to making the shaft of a railway motor very stiff. Its diameter is now considerably larger than in motors of equal capacity used for other purposes.

CHAPTER XI.

MANAGEMENT AND REPAIR.

THE perishable parts of a street railway motor are the bearings, the brushes, the commutator, and the windings. These require constant inspection and repair.

The bearings of a street railway motor must be very frequently inspected. Worse results than mere looseness and rattle are entailed if they are allowed to wear too long, for they are what centralize the armature in its field. If the bearings are allowed to wear so that the armature strikes the pole pieces, the former is very likely to be seriously injured if not completely destroyed, because not only is the winding ruined by the laminæ forcing through its insulation, but the teeth of the core itself are often so bent and broken as to consign it to the scrap heap. Moreover, once decentralized the pole pieces pull the armature against the bearings with great power.

The best way to keep track of railway motor bear-

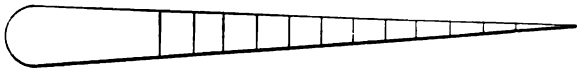

Fig. 145.—Gauge for Measuring Clearance.

ings is to inspect the armature clearance. For this purpose a gauge should be provided, such as is shown in Fig. 145, and on this gauge should be marked the minimum amount of clearance that it is advisable to run for different motors. This will vary with the kind

of bearings used and the car miles per day; but, as a general rule, 3-64 of an inch is considered exceedingly close work.

This taper gauge may be introduced through the hand hole which is usually provided at the lower part of the motor; but, as it is not always convenient to do this, the following method of inspecting the clearance has sometimes been used. It is illustrated in Fig. 146. Two holes are drilled in the motor casing on a line

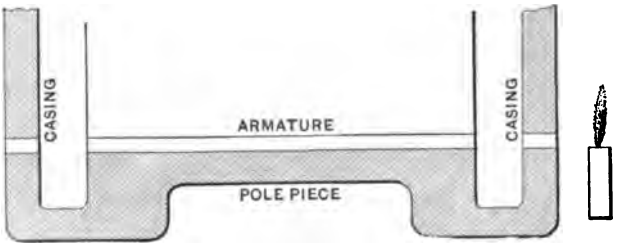

Fig. 146.—Method of Inspecting Clearance.

with the clearance and with each other. They should preferably be drilled so as to be in line with one of the lowest pole tips in the motor, if it is of the four-pole type such as is commonly used to-day. By holding a candle in front of one of these holes and applying the eye to the other, the clearance can at once be inspected though not measured. When not in use these holes are preferably closed by pipe plugs or by a special plug manufactured for the purpose.

The casing of the motor is not liable to any serious accident. It will undoubtedly outlast any other part of the motor. However, it should receive general inspection with reference to the nuts and bolts which hold it together and support it. The vibration of a street railway motor equipment is so great that almost any

nut that is not secured by a spring cotter will shake loose.

The motor suspension should have careful inspection. This is a part of the truck which very frequently fails, and by dropping one end of the motor into the street, produces disastrous results. Springs, nuts, bolts, and bars should be carefully scrutinized. The repair of such parts as these is an obvious mechanical matter.

The windings of a street railway motor are deserving of more attention than any other part of the equipment, partly because they frequently need repair and partly because their inspection is a matter in which simple observation does not suffice. The troubles of windings may be naturally divided into those of the field and those of the armature. The former will be first considered.

In general it may be said that there are only two disasters which can overtake a winding: (1) the failure of its insulation and (2) the failure of the copper conductor. The failure of the insulation involves short circuits; that is to say, contact between adjacent wires or conductors, and grounds, which may be described as contact between wires and adjacent metal portions of the casing. Failure of the conductors may be simply described as an open circuit.

The principal faults which occur in field coils are short circuits and grounds. The latter are most frequent and should be first tested for. The usual way to test for a ground is to try to ring a magneto-bell from the field coil terminal to the casing. A convenient and much-used method is to take a circuit from the 500-volt system having five lamps in series, as shown in Fig. 147. One of these may be applied to the metal casing and the other to the field wire. The

lighting of the lamps shows a contact between field wire and casing, that is to say, a ground. In making this test it is well to make sure that the ground screw on the motor is disconnected, because otherwise the test will inevitably show a ground which is not a fault.

A ground in a railway motor field coil is equivalent to short circuiting or cutting out of part of the field, because the current escapes to earth through this path before it has traversed all of the field coils. This makes the field very much weaker than would normally be the case. A weak field in a railway motor is accompanied by an enormous demand for current when the motor is in operation, resulting in heavy flaring and flashing at the commutator. If, therefore, a ma-

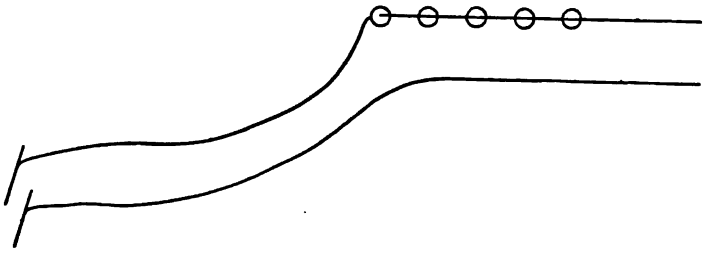

Fig. 147.—Testing Circuit.

chine comes in with the commutator and adjacent parts badly burned, a weak field may at once be suspected.

If the field coils ring or otherwise test clear of the casing it is probable that they are in good order; but this is by no means certain. A coil may be short circuited on itself and thereby be cut out, producing a weak field, even without the usual accompanying ground. If the resistance of the bobbins is known, a good method is to measure them with an ohmmeter or bridge. If the result shows seventy-five, fifty, or twenty-five per cent. of what it should be it may be in-

ferred at once that one, two, or three of the field coils are cut out, while if the system tests out absolutely short circuited, it will be known that all of them are cut out.

In this connection it is well to mention that it is highly advantageous to know the resistance of the various circuits in the various makes of railway motor and to have them conveniently tabulated for reference. There is no better criterion of the condition of an electrical circuit than its resistance. If its resistance is what it should be, the circuit may be assumed to be free from every fault excepting grounds. If it is less, a short circuit is to be looked for. If it is more, poor contacts or even open circuits may be sought.

Having located the trouble in the field coil, the latter should be replaced and the old coil inspected at leisure. It will often be found that the coil cannot be patched or repaired, but must be sold for old copper. If, for instance, in unwinding the coil a little burned spot is found where two turns have touched each other, it is fair to assume that other spots exist all through the coil, and even if it should be found that the repairing of this broken place in the insulation should restore the coil to its proper resistance, it ought still to be regarded with a great deal of suspicion. It is never wise to take chances with railway-motor field coils. A weak field means not only injury to the field coils themselves, but almost invariably the certain destruction of the armature and commutator. After the faulty coil has been found and replaced, a reasonable amount of dependence may be placed upon the others; but the locating of a fault to a closer degree than this should not be followed for purpose of repair, although it is well to be informed of the exact nature of the trouble,

so as to avoid it in future by better construction and arrangement.

The armature winding is another and most important item in railway motor repair. The troubles that obtain in an armature are like those in a field—open circuit, short circuit, and grounds. Grounds are most to be feared, and must be tested for in the same way as the field coils. A ground in an armature or, for that matter, in a field coil may be conveniently located

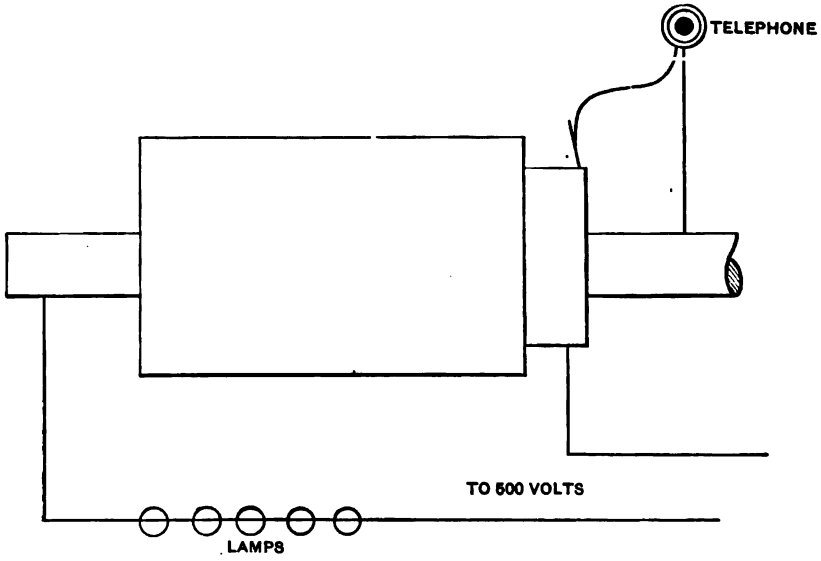

Fig. 148.—Locating a Ground on an Armature.

by the following method. Current is passed through the armature and the ground by means of a test circuit such as was shown in Fig. 147. A telephone receiver should be connected with one terminal firmly to the shaft. The other terminal may then be touched to various portions of the commutator until a bar is found on which the click in the receiver, when the touch is made, is a minimum or practically *nil*. This

is the bar nearest the grounded point and probably that to which the grounded bobbin is connected. This method is very accurate. It is shown in detail in Fig. 148. In applying this test to field coils, current should be sent through one of the field terminals to the motor case. One terminal of the telephone may then be connected to the motor casing and the free terminal touched to either terminal of the field circuit. That giving the fainter click is nearest the ground. By opening the insulation on the connections between the various coils a point may be found where the click is

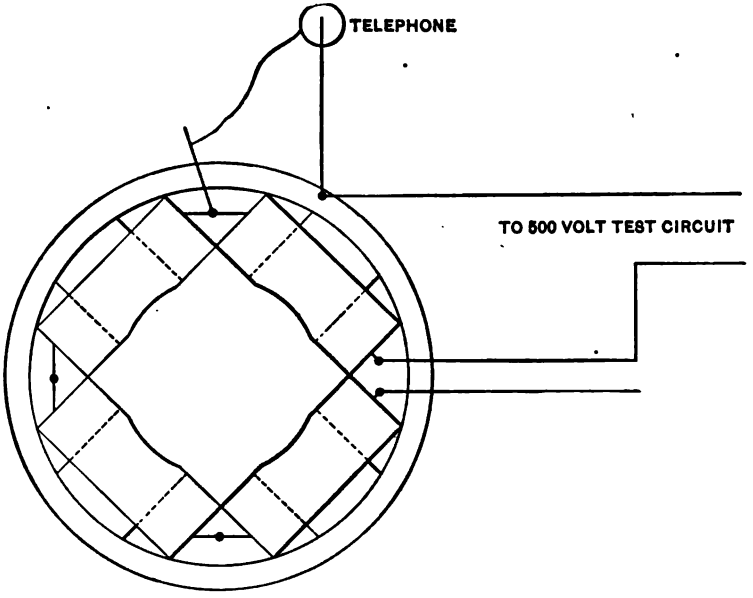

Fig. 149.—Locating a Ground on a Field.

faintest of all. The grounded coil may be located by considering the fact that if the actual point of grounding were touched with the free terminal, there would be absolutely no click in the receiver. The diagram Fig. 149 will also assist in making this plain.

Open circuits in the armature are usually indicated by severe local burning on the commutator. The open-circuited coil is usually connected between the badly burned bars. When the commutator is in action there will be periodical flashing, which will keep step with the revolutions as the open-circuited bars pass under the brushes. An open-circuited armature will measure twice its normal resistance between any two bars on the quarter, and between the bars bridged by the open circuit it will measure four times the normal resistance of the armature between brushes. Open circuits are usually found in the armature head where the wires are frequently burned off by large flaring arcs at the brushes. Often the wire next the commutator bar is broken off or has come unsoldered, and if the open circuit does not appear in any of these places it may be sought at the ends of the slots where the coils bend sharply in passing from slot to slot. An open circuit can sometimes be patched by carefully cleaning the two ends of the burned wires and soldering them together with a sleeve of thin sheet copper tinned on the inside. It is a method requiring some skill and much patience, but it will sometimes answer in cases that appear quite desperate.

Another accident that may overtake an armature is that a single coil or, more often, a pair of coils burn out. This is usually caused through the bridging of two adjacent bars by a thin film of copper or carbon dust. Indeed it is surprising to see how small a film will often suffice to burn out a heavy copper coil. A temporary expedient may be applied by cutting the commutator lead of the burned-out coil and then arching solder across the two commutator bars to which it is connected. It may be added that this expedient may also answer for temporary relief in the case of

an open-circuited armature. For permanent repair the coil must be renewed, and unless the armature is very new it seldom pays to introduce one new coil and retain the others, because it is necessary to disturb practically all the coils on the armature to free the injured one, a process which cracks and destroys the insulation. Moreover, in renewing a coil in this way at least one-half of all the commutator bars must be unsoldered. Repeated soldering renders the ends of the coils very brittle and increases the chances of their breaking off close to the bars.

On a railway motor armature, it must be remembered, a ground also constitutes a short circuit. If, for instance, the current enters one of the brushes of the armature and before it has traversed many of the armature windings, finds a path on the core, it will fail to traverse any other windings between that point and the ground. It is therefore necessary to make insulation between copper and iron twice as thick as would be necessary for ordinary dynamo work at the same voltage.

When selecting railway motors for an equipment it should be borne in mind that the motors are likely to divide the load unequally between themselves, and if possible a few preliminary tests should be made to choose motors that are suitable to run together. The reason for this difference in the performance of two motors, apparently exactly alike, is frequently found in the quality of steel of which the frames are made. Steel castings vary in their magnetic qualities, and the same current passing through similar coils will very frequently give different strengths of fields in two like motors and will, therefore, cause different outputs. When connected in series, the motor with the high counter E. M. F. will take most of the load, while in

parallel the reverse will be the case, and if this difference be great, the load may be so unevenly divided as to heat one motor badly while the other will not work up to its full capacity. To test for this the two motors may be connected together by means of a common gear wheel, as shown in Fig. 150. Their speeds are then

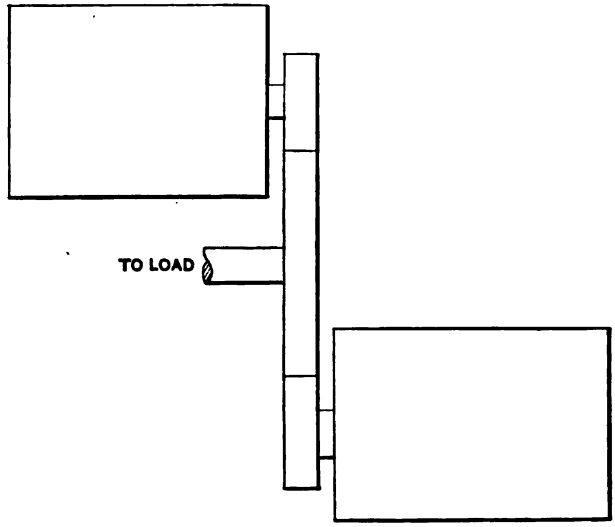

Fig. 150.—Mechanical Connection Used in Method of Pairing Motors.

necessarily alike. The motors should then be connected in series so as to drive the connecting gear in the same direction, and sufficient voltage applied to the two motors to run them up to normal speed. It is then obvious that each motor has the same speed and the same magnetizing currents, and if they divide the voltage unevenly between themselves they are not well suited to run in pairs. The measurement should be made with two voltmeters, one at the terminals of each motor, or, if only one voltmeter is at hand, it

should be connected with a double-pole double-throw switch, as shown in Fig. 151, thereby enabling a change to be made in the connections very quickly, so that the readings may be simultaneous as nearly as may be. A

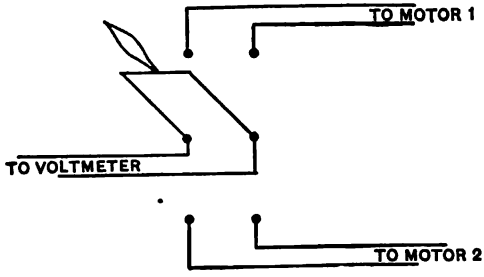

Fig. 151.—Voltmeter Connections in Pairing Motors.

still better method is to use a differential voltmeter connected as shown in Fig. 152, which will indicate the difference between the impressed E. M. F. on the two motors. This difference should not exceed ten per cent. of the total voltage. It is advisable, if possible, to connect the gear wheel common to the motors to a friction brake of sufficient power to load both motors to their full capacity and to try their action on

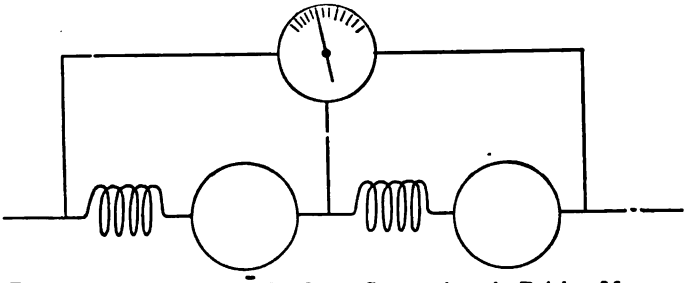

Fig. 152.—Differential Volt Meter Connections in Pairing Motors.

different loads. When connected, as shown in Fig. 150, the motors divide the load in exact proportion to

the impressed E. M. F. on the armatures. Thus, if one motor shows a counter E. M. F. of 120 and the other a counter E. M. F. of 80, the first motor will carry fifty per cent. more of the total load than the other when operating in practice. Two motors may sometimes be adapted for mutual operation by placing paper between the edges of the motor case of the motor having the stronger field. It is, however, more of a laboratory expedient than a method to be employed in actual service.

The repairs on electric railway motors may be very much reduced by a careful system of inspection. Mechanical inspection is given, of course, to a greater or less extent in every railway car house. The bearings are examined, nuts are tightened, and brushes and commutator inspected, but a thorough electrical inspection is very much less frequently made, because such inspection is usually more troublesome. The trouble, however, is repaid in the end. If, for instance, faulty insulation is detected before it breaks down, causes a weak field, burns out the armature, and destroys the commutator and brush holders, it is certainly worth while to spend a few moments on that inspection. The following convenient method of making such examinations is therefore given.

The car house is fitted with an insulated section of track, together with a corresponding insulated section of trolley wire. The feeders for this section of track and trolley wire pass to a little room suitably located near the insulated section. At this station are provided switches whereby the trolley wire can be connected to the power feeders and the rails to ground. A double-pole double-throw switch is most convenient for this purpose, as it will permit a single motion to transfer the car circuit from the power feeders to the

testing circuit. The connections may be conveniently made, as shown in Fig. 153. The car is first switched on to the ohmmeter and the resistance of the equipment on every notch of the controller is quickly observed and recorded. The ohmmeter is then cut out, the ground connection of the car is broken by an appropriate switch, and a 500-volt pressure is applied with a voltmeter in series, after which the deflection of the latter instrument is noted. This deflection is then compared with those previously taken, preferably

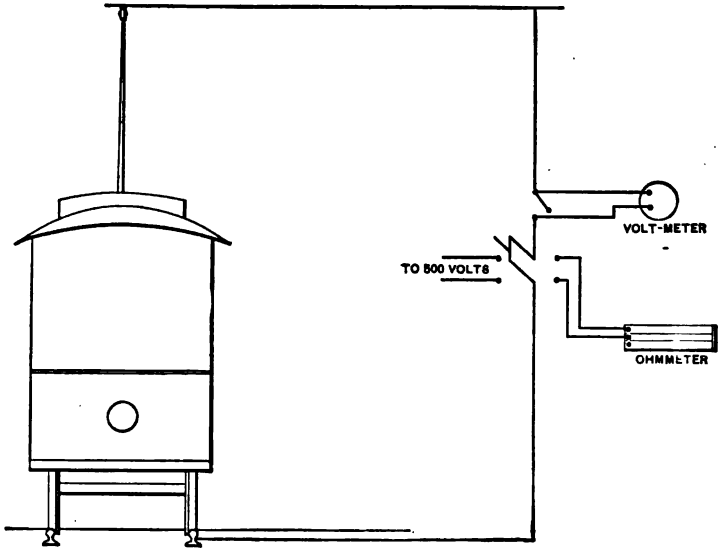

Fig. 153.—Connections for Rapid Inspection Test.

those on the first notch of the controller when all of the resistances and other parts of the equipment are in circuit. From these deflections the actual insulation resistance of the equipment in ohms may be calculated, but a quantitive determination is not necessary for the purpose of the test, for a limiting deflec-

tion can be set and any car in which this deflection is exceeded can be marked down for repairs. The results should be tabulated in a suitable logbook.

These measurements take but a few moments per car, and much may be learned from the records obtained. For instance, if it is noted that the resistance of a car on a certain notch becomes less and less from day to day, it may be suspected that some of the resistance coils are gradually short-circuiting on each other. If, on the other hand, the resistance measurements become larger from time to time, an inspection will probably show poor contacts in the controllers, on the commutators, or elsewhere in the motor circuits. The insulation resistance of the car from trip to trip may be carefully watched, and frequently, long before a ground can occur and create serious damage, it can be anticipated and removed.

If the car is found to be defective and departing considerably from the measurements that it usually gives, the fault can be run down at once while it is standing on the test section. If, for instance, the resistance is low on those notches where portions of the resistance are cut in, and is intact on those notches in which the resistance is cut out, it may be assumed at once that the trouble is in the resistance, and the same method of exclusion also suffices to locate the actual section of the resistance in which the trouble lies. If the trouble is not found in the resistance, first one and then the other motor may be cut out and the measurements made and compared with those taken at a time when the car was known to be in good condition. Trouble in the controller can be determined by repeating the tests with the controller at the rear of the car. If the measurements thus obtained are found to compare favorably with those previously made, it may be

assumed at once that poor contact or leakage exists in the first controller. The heater circuit may also be tested by this system.

A great advantage in this method of testing is that the results are of necessity a matter of record, and not only assist in locating faults and anticipating trouble, but serve as a means of comparing different equipments and different methods of construction.

As this book may fall into the hands of motormen or prospective employees in that capacity, it has been thought desirable to devote a few paragraphs to car management and emergency repair. As far as management is concerned the motorman usually receives careful instructions. He learns or should learn that there are certain notches in the controller which are running notches and certain other notches which may be considered starting notches, and which should only be used for short intervals of time. He should also know that he ought not to pass slowly or stop between notches, but should throw the controller from notch to notch with a snap. The car should be allowed to gain headway on one notch before moving the controller handle to the next one. Sudden flushes of power to the motors are very injurious to the commutator and windings, and, moreover, will certainly be detected by expert inspection.

In reversing the car, in case of an emergency, it is necessary to turn the power on very slowly. The first notch will usually be sufficient to cause a powerful check on the speed of the car. The second will stop the motor, and the third may give a reverse rotation. It is well known that the maximum retarding effect is attained when the wheels are not skidding on the track. For this reason reverse current in an emergency stop should be limited to the first two notches. In addi-

tion it may be stated that several notches under such conditions are likely to call for enough current to blow the fuse and thereby prevent reversing at a time when it is most needed.

If the car refuses to start there is probably an open circuit. It may be sought in the following places:

1. Trolley may be off; easily seen and removed.

2. The hood switches may not be thrown; also an obvious omission. It may be remembered to advantage that in some cars—in fact, in most of them—the hood switches on the two platforms are in series and therefore both must be closed.

3. The controller may contain an open circuit. This can be determined by seeing whether the car works with one controller and not with the other. If this is the case, open the hood switch, then open the case of the defective controller, and look for fingers which fail to make contact. If the contacts are in good condition look for wires which may have shaken loose from their connecting blocks, or improperly closed cut-out switches or similar matters.

4. The fuse may be blown, and this frequently is the trouble. It should be one of the first things to be inspected.

5. The motor brushes may not be making contact. One of them may have dropped out altogether. If any one of them is making defective contact, it opens the entire circuit on first notch.

6. The ground may be poor. This is a frequent trouble. In such cases the car may have run on a dirty section of track or for some other reason is insulated from the rail. It is easily possible for the lamps to be burning at normal brilliancy, and yet the ground

not sufficiently good to permit the car to start. A common method of procedure in such a case is to take a switch iron and wedge it firmly between the wheel and the rail on the opposite side from that in which the car is to move. This will frequently improve the ground sufficiently for the purpose. Sometimes the ground is poor because the rail bonds have been broken, in which case the car may be started by connecting a flexible wire to the truck frame and touching the free end of the next rail back. In such a case the location should be noted and reported to the proper authority, for it is by such experiences that broken bonds are often located.

If a motor armature flares and sputters at the commutator, a weak field or some kindred evil may be inferred. The injured motor should be cut out and the trip completed with the other motor. A convenient method of determining whether the trouble is in the motor or controller circuits is to give the controller notch after notch, and if on reaching the parallel notches the car starts, it may be at once inferred that the trouble is in the inactive motor circuit. The inactive motor will be readily detected by the absence of sparking at its brushes. If, however, the car fails to start on any of the notches the trouble is located in some circuit common to both motors. This includes the trolley, the fuse box, the controller, and the ground.

For making temporary repairs the motorman should carry with him the following equipment:

1. Plyers.
2. Roll of tape.
3. Short lengths of flexible cable.
4. Sandpaper for smoothing controller segments.

5. Extra brushes and springs therefor.
6. Wrenches, hammer, screw driver.

With these tools and a little careful study he should be able to start his car unless it has encountered some accident which necessitates repair-shop facilities.

CHAPTER XII.

THE DESIGN OF A STREET RAILWAY MOTOR.

THE subject of this chapter is one which can only be very superficially treated here. Many able books have been written on the subject of dynamo and motor design, and those who wish to go further in the subject must refer to them. It is proposed to give here a general idea of the method of attacking the problem and to abridge detail.

The data and formulæ which are used in computing the electrical and mechanical dimensions are varied in character. Some are rational, some are empirical, and many dimensions are deduced from practical facts with which the designer must become acquainted. For instance, he may calculate the number of wires on the armature to work under the impressed voltage with mathematical accuracy, but in computing the size of those wires and their arrangement upon the armature he must consult his experience with reference to heating and operation, cheapness of construction, and convenience of repair. The conditions often conflict, and the skillful designer is he who can use good judgment in giving each condition its proper consideration. A good dynamo designer, it might almost be said, is born and not made. No one can do good work by strict adherence to formulæ.

The object of this chapter will be best served by

selecting a type of motor and working out some preliminary calculations.

For this purpose we will assume our problem is to design a 35-h. p. motor adapted to operate at 500 volts and 500 revolutions, the same to be used for ordinary street railway work. We shall of course adopt the standard four-pole series drum winding. This motor will be frequently started and stopped and seldom run for a long time at full load. In short the work will be of an intermittent character, and it therefore follows that we can work the iron and copper much harder than would be permissible if constant and full load were to be maintained at all times. It is very necessary to take advantage of this feature, because a railway motor should above everything else be as light as is compatible with good operation, and it is obvious that if we work the iron at greater density and the copper at greater current intensity, we shall have less metal in the motor, reducing therefore both its weight and cost. To illustrate this point it may be mentioned that it is the standard practice of a prominent electric company to make motors for railway work at a temperature rise of 75 degrees centigrade after a run of one hour at full-rated load. This is, however, the most severe work that it is expected the motor will ever be called upon to perform.

The first point to be attacked in the problem is usually the size of wire to use on the armature. It is the practice with modern motors to use a large slot and pack many conductors deeply therein; and, from practical experience with current carrying wires packed in such slots, we may safely assume current density of 2500 to 3000 amperes to the square inch in cases of intermittent load of this character. The motor at full load will carry a current of 60 amperes, allowing

for an efficiency of a little over 85 per cent. Each wire will carry one-half of this current and the area of the armature wire will be

$$\frac{30}{3000} = .01 \text{ sq. inch.}$$

It has been found that motors of this size and output are conveniently wound with wire coils, ribbon-wound coils being suitable for the larger sizes only. The gauge of wire on the Brown & Sharp system which most nearly approaches this section is No. 9, which would be a suitable wire for this purpose.

The next problem is the number of these wires that shall be used, and that depends entirely upon their speed and the strength of the magnetic field in which they are revolved. This point is one that calls for the very best judgment of the designer. The temptation is to make the field comparatively weak and use a great many wires, because that means a light casing and a light armature; but, on the other hand, if this be carried to too great an extent the commutator is likely to spark badly and the resistance of the armature will be so great that the loss in the copper will be excessive. If we were at work on a stationary motor we should also have to consider variation in speed, which in such a case it would be desirable to keep constant; but with a railway motor the speed is essentially variable, and we need not pay so much attention to this feature other than to make sure it gives its rated speed at full load.

Without entering into a deduction which would be out of place here, it may be stated that the number of conductors on the four-pole series-wound motor armature, the speed, and the strength of field are related as follows:

$$E = \frac{2NCS}{100,000,000},$$

where E = the back e. m. f. of the armature, N = the number of lines of force emanating from one pole, C = the number of conductors, and S = speed of the armature in revolutions *per second.*

To determine the probable back e. m. f. of the motor armature we must draw on the storehouse of experience. The field in series with the armature will take 5 per cent. of the impressed voltage. The armature will take about 4 per cent., a total of 9 per cent. Nine per cent. of 500 is 45 volts, and leaves 455 volts as the back e. m. f. of the armature. Substituting the known values, we have

$$455 = \frac{2 \times 500 \times NC}{60 \times 100{,}000{,}000},$$

whence $NC = 2{,}730{,}000{,}000$.

Now comes the finest point of judgment in the entire design. The field multiplied by the number of conductors equals 2,730,000,000. What shall be the separate factors? If the design were that of a stationary shunt motor, the case would be easy, for then the cue would be to cut down the armature wires to a minimum workable quantity and employ as strong a field as the core losses of the armature would permit. Such a machine would be notably sparkless, of low armature resistance, and hence of excellent constant speed regulation, though quite heavy.

In railway work this will not do. The motor must be light. A moderate armature resistance is not objectionable, because it tends to prevent heavy flushes of current when the controller is turned on suddenly. The great requisite of a railway motor is torque, or starting effort, and torque increase in direct ratio with the number of armature conductors.

Another point must be taken into consideration. On starting, the current in the motor may rise to over

a hundred amperes, and it is on starting that great torque is required. If we work the steel of the field too near the saturation point, the heavy starting current will not increase the field strength perceptibly, and while the current in the armature itself will of course increase the torque, it is very desirable that the heavy current swell N also, to augment T. We, therefore, are checked in working the steel case to the limit, yet we must have it light. It would seem that it was best to make C as large and N as small as practical limitations will allow. This is indeed the case, but note well the practical limitations.

If we make N too small the motor will spark. Our only guide is practical experience and a few empirical formulæ deduced therefrom. If we make C too large the armature will be costly to manufacture and repair.

If we make C too large the armature will be clumsy and will have a fly-wheel capacity which will make it wasteful of current in starting and stopping. Experience has shown that motors of this size, speed, and type, having over 800 conductors, spark; and with less than 600 conductors the weight of the motor begins to tell. Experience alone is responsible for placing these limits. They are the outcome of hundreds of experiments on this size of motors, and are more accurate than any formulæ could possibly be.

To determine the relation of the factors N and C, Mr. A. E. Weiner has given the following table for high-speed dynamos or motors:

KW. CAPACITY.	TOTAL USEFUL FLUX.
.1	200,000
.25	333,000
.5	550,000
1.	880,000
2.	1,530,000
3	1,875,000

KW. CAPACITY.	TOTAL USEFUL FLUX.
5.	2,550,000
10.	4,000,000
15.	5,700,000
20.	7,200,000
25.	8,500,000
30.	9,900,000
50.	15,500,000
75.	22,000,000
100.	28,000,000
150.	39,500,000
200.	50,000,000
300.	70,000,000

In using this table for a four-pole dynamo, the total useful flux represents that of *both* north poles or *both* south poles. This motor is about 26 kw. capacity, and from the table we find a total useful flux of 8,500,000, half of which divided into 2,730,000,000 gives 642 conductors, a partial check on the figures and somewhat low because the table applies to stationary apparatus. Such tables as the foregoing are of a most general character. The total useful flux depends upon and varies inversely with the speed. The same armature at twice the speed requires half the flux, other things being equal. Such data as these may assist, but they cannot replace careful judgment founded on ripe experience.

Having thus located the number of conductors between limits, it remains to select the number accurately, and to that end we must consider certain advantages of construction. We must so choose and arrange the number of turns per coil that the bunch of coils in the slot has a symmetrical section, for otherwise it will not pack nicely. Three, four, five, and possibly six, turns per coil are permissible. There will be as many coils as commutator bars, and the number of commutator bars must be odd.

For mechanical reasons it will not be well to have

the armature dimensions exceed 16 inches, and this helps us to determine the number of slots and the arrangement of the coils therein.

For magnetic reasons—namely, heating and sparking—the slot and tooth must be about the same width and the depth of the slot must be at least twice its width. In order that the coils may slip on, the slot must be straight.

Further, it is customary in modern railway motors to bunch the coils well together, so as to have strong, substantial teeth and also to make them easy to wind.

Twenty-four conductors per slot is not at all uncommon. If we select 24 conductors per slot and use 31 slots, we shall have in all 744 conductors, and at 8 conductors or 4 loops per coil we shall have 93 commutator bars. This arrangement will wind reentrant because of the odd number of coils, but, before we adopt it, it will be necessary to see whether the coils will conveniently pack in place in a slot of proper shape, and whether after adopting a suitable breadth of

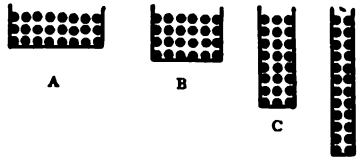

Fig. 154.

tooth the armature diameter will be too great. As to arrangement of wires, we may adopt any shown in Figure 154.

A in Fig. 154 is absurd. Its great width and shallow depth, combined with the proper tooth, would entail a diameter of armature far too great. *B* also violates the rule that the depth of the slot in a toothed armature should exceed its width by at least 2. *C*

is nearly right, and D is altogether too deep, for it will make the tooth of high reluctance and long, narrow,

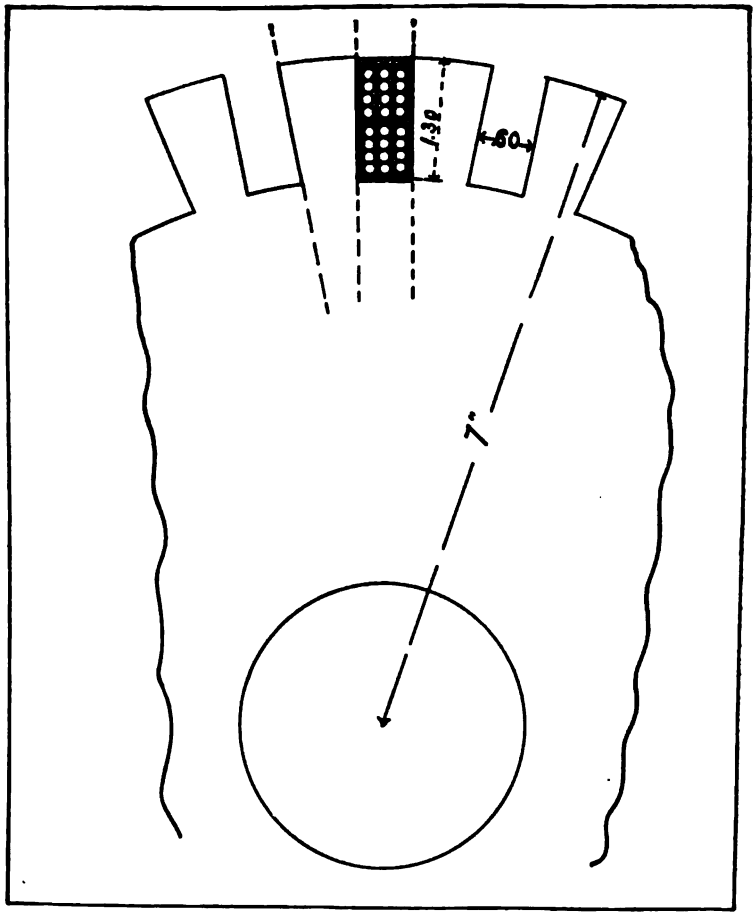

Fig. 155.

and delicate. The following formula has been recommended to determine slot width:

$$w = \frac{\pi d}{2n},$$

where w is the width of the slot, d the armature diameter, and n the number of slots. Adopting 12 as a provisional figure for d, we get

$$w = \frac{3.1416 \times 12}{2 \times 31} = .61 \text{ inch, nearly.}$$

We are practically compelled to adopt the slot C, Fig. 154; first, because it has an even number of conductors from top to bottom, which is very advantageous for coil arrangement; and second, because it is the only possible shape which has this advantage and at all approaches the theoretical desideratum. Moreover, the number of wires in depth is an even multiple of the loops per coil. The width of the slot must be

1-16 inch insulation, ...	.0625
Three double cotton covered wire No. 9, .	.385
Two separators, 1-64 inch each, . . .	.03125
1-16 inch insulation, ...	.0625
Total, ...	.54125

To this it is advisable to add one per cent.

for loose packing, ...	.054
	.59525

A slot .6 inch in width would be suitable and a convenient figure.

The depth of the slot works out as follows:

Clearance, 1-32 inch, ...	.03125
Wood filler, 3-32 inch, ...	.09375
Insulation, 1-32 inch, ...	.03125
8 No, 9 wires double cotton covered, . .	1.027
1-16 inch between coil bunches, . . .	.0625
1-16 " bottom of slot, ...	.0625
	1.30825

The ratio of depth to width is

$$\frac{1.3}{6} = 2.2,$$

and approaches theoretical conditions nearly enough

for present purposes, although a little deeper slot would be preferable. It is now necessary to make a drawing of the core disk and see if there is any mechanical or magnetic objection to the shape of the disk. One or two slots will be sufficient. Making the slot and top of the tooth the same width, we get an armature diameter of

$$\frac{.60 + .60 \times 31}{\pi} = 11.8.$$

A 12-inch disk suggests itself because it uses a standard die. As the slot is designed, the conductors are to be insulated as follows: Three coils are to be stacked together with 1-64-inch separators between and are to be served with 1-32 inch of tape. The slot is to be lined with 1-32 inch of fuller board and mica, and after the bottom side of one set of coils and the top side of another are installed therein, a wood filler is added, and the slot is full. If desired, the slot may be made 1-8 inch deeper, the coils served with 1-16 inch of tape, and the fuller board omitted.

Before accepting 12 inches as an armature diameter it is wise to make a preliminary calculation to see if an armature of that diameter properly fluxed and carrying current to that extent on its circumference will overheat.

To do this we calculate what may be called the circumferential density, which equals

$$K = \frac{CI}{\pi d},$$

where K = the circumferential current density.

C = the number of conductors.

I = the current in one of them.

d = the armature diameter.

Applying the above, we have

$$K = \frac{744 \times 30}{3.1416 \times 12} = 592.$$

Experience has shown that in this class of motor, 500 is a limiting value for this figure. The qualification is rather loose, for if the speed were lower a higher value would be permissible, but it is accurate enough for a preliminary estimate, and may save a second calculation when we come to accurately ascertain what the heating will be.

Reversing the last formula, we have

$$d = \frac{CI}{\pi K},$$

and applying we get

$$d = \frac{744 \times 30}{3.1416 \times 500} = 14.2 \text{ inches.}$$

Therefore a 14-inch disk, a convenient size, will answer.

Making the drawing as shown in Fig 155, it will be

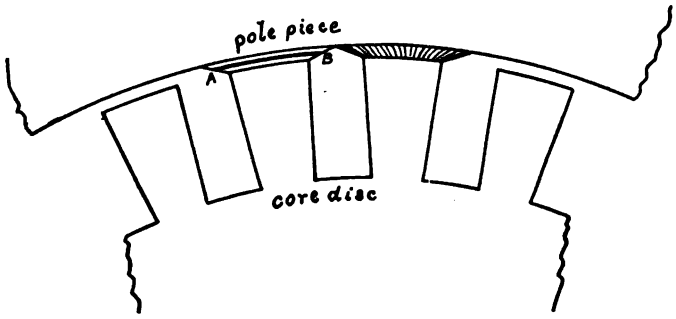

Fig. 156.

noted that a strong powerful tooth develops and that the root of the tooth is nearly equal to the width of the slot.

The length of the armature must next be determined, and in this we are limited. More than 15 inches will

crowd the axles, bearings, and commutator. There are available but 52 inches from flange to flange between the car wheels. Of this 8 must be given to the pinion and casing, and 8 to the pinion bearing, 12 to the armature ends if the straight-out plan is used, 4 to the commutator, and 6 to the commutator bearing, a total of 38 inches. All of these figures are reasonable. Clearly, if we hope for brake-rod space at the sides of the motor, we must be economical. Much of the space may be saved by overhanging the commutator and armature over the bearings.

The total flux from one pole is

$$\frac{2,730,000,000}{744} = 3,669,300.$$

The limit at which it is advisable to work the iron of a high-speed multipolar armature is 50,000 lines to the square inch. Since the flux from a single pole divides, one side of the disk carries but half the total effective flux. This means that we must have at least

$$\frac{3,669,000}{2 \times 50,000} = 36.69 \text{ square inches}$$

of iron in the cross section of the flux path. One dimension of this section, the distance from the root of the tooth to the shaft, which must be at least 3 inches, can be calculated at once, and is 4.2 inches, whence we obtain

$$\frac{36.69}{4.2} = 8.7 \text{ inches}$$

as an armature length.

This completes the preliminary calculations for the magnetic and electrical dimensions of the armature. It is now necessary to make calculations to determine whether or no the armature will overheat, and before

doing this the following quantities must be computed (the process is simple mensuration and will only be indicated):

Surface of armature, $14 \times 3.1416 \times 8.7$, = 383 sq. in.
Surface of ends carrying straight-out windings, $14 \times 3.1416 \times 12$, . . = 528 "
Surface of ends of cylinder, $2 \times 3.1416 \times 49$, = 308 "
Total radiating surface, ... = 1219 "
Cubic inches of iron in armature body, $(5.7^2 - 1.5^2)\, 3.1416 \times 8.7$, . . . = 826 nearly
Cubic inches of iron in teeth, $1.30 \times \left(\frac{.56 + .82}{2}\right) \times 31$, ... = 27.8
Flux density in armature, . 50,000 lines per sq. in.
Flux density in teeth, 7 teeth per pole, ... 87,300 lines per sq. in.
Length of active wire on the armature, $\frac{744 \times 8.7}{12}$, ... 539 ft.
Length of dead wire on the armature, estimated, 774 "
Total length of wire on the armature, . . 1313 "
Resistance of this wire, at .976 ohm per M ft., 1.28 ohms,

From these data the heating losses of the armature can be calculated with moderate accuracy.

The wire loss in the armature is equal to

$$I^2R = 30^2 \times 1.28 = 1150 \text{ watts.}$$

The hysteresis loss of a cubic inch of average iron worked as is the armature at 1000 cycles per minute at a density of 50,000 lines per square inch, as calculated by Steinmetz' formula, is .156 watt. Therefore, the core loss due to hysteresis is

$$.156 \times 826 = 129 \text{ watts.}$$

At 87,000 lines density and 1000 cycles per minute a cubic inch of iron absorbs .388 watt. Therefore, the teeth absorb

$$27.8 \times .388 = 10.8 \text{ watts, nearly.}$$

To this we must add an eddy current loss which will

depend on the thickness of the laminæ and the quality of the insulation between them. If we assume the insulation to be perfect and the core disks to be 20 mils thick, the following formula is said to give approximate results:

$$P = e \times (2N)^2 \times M,$$

where P = the power lost in eddy currents, in watts.

M = the mass of iron in cubic feet.

N = the revolutions per second, whence $2N$ = the magnetic cycles per second.

e = an eddy current factor depending on the density of flux and the thickness of the laminæ (in this case it is given at .072).

Applying we get

$$P = .072 \times (16\tfrac{2}{3})^2 \times .49 = 9.8 \text{ watts.}$$

We cannot hope for any such value in ordinary core construction. We shall be lucky if we escape with 50 watts loss, the increase being due largely to insufficient insulation between the disks.

The total losses of the armature in watts are

Wire loss,	1150
Core loss,	129
Tooth loss,	11
Eddy currents,	50
Total,	1340

and the watts per square inch of radiating surface are

$$\frac{1340}{1219} = 1.1.$$

This in an open-frame dynamo would make a very hot machine at continuous load. The temperature of the armature would rise at least 55 degrees centigrade, and in the inclosed motor the rise would be at least 75 degrees centigrade in one hour's running. In railway

work, however, such temperatures as this must be endured if light motors are to be produced.

We may accept the armature design as satisfactory, subject, of course, to certain refinements of calculation which the exigencies of the field curcuit design may demand.

The design we have evolved is as follows:

Diameter,	14 inches
Length,	8.7 "
Slots,	31 "
Slot dimensions,	6 × 1.3 "
Wire,	No. 9 B. & S.
Turns per coil,	4
Conductors per slot,	24
Total conductors,	744
Radiating surface,	1219 sq. inches
Losses,	1315 watts
Watts per sq. inch,	1.1
Number of commutator bars,	99
Probable rise of temperature on one-hour run,	75° C.
Lines of force through armature,	3,669,000

The next problem is to determine the dimensions of the magnetic circuit, and to do this we must ascertain the number of lines of force it is to carry.

The armature will require 3,669,000 lines per pole in order to generate a back e. m. f. of 455 volts. The *CR* drop through the armature at full load will be

$$\frac{1.25}{4} \times 60 = 18.75 \text{ volts},$$

leaving 26.25 volts to force the current through the field. This will probably be too much. It is better, however, to disregard these considerations for the present, for we can easily adjust speed and voltage by simply varying the flux slightly in a subsequent calculation. Accepting 3,669,000 lines of force as the useful flux, it remains to assume a provisional leakage co-

efficient, for the field magnet must generate both the useful flux and that lost by leakage. In a motor of this capacity and of the radial pole type, the leakage coefficient is usually about 1.30—that is to say, for every 10 lines of force in the armature there must be 13 in the field. The total flux is, therefore,

$$3{,}669{,}000 \times 1.3 = 4{,}769{,}700.$$

It is now necessary to design a field magnet which will carry this flux, and then to wind upon it coils of sufficient magnetic power. As will be noted from the drawing, Fig. —, the shell of the motor will carry but half this flux, for the magnetism of the pole piece divides, half going one way and half the other. This shell will be of cast steel and should be worked at about 80,000 lines to the square inch, thereby making the area of the shell section between pole pieces

$$\frac{4{,}769{,}700}{80{,}000 \times 2} = 29.8 \text{ sq. inches.}$$

As soon as the mechanical inclosure is designed of sufficient proportions to accommodate the internal parts of the motor, it will only be necessary to thicken the shell until this area of section is attained.

The next point is the internal diameter of the cylindrical shell. This is very important, for it fixes the length of the pole pieces and the room for the field windings. Fortunately, we are able to calculate the major portion of the exciting strength without any field magnet design. This is the ampere turns necessary to force the flux through the gap space. We may then assume a provisional length of magnetic circuit and calculate the ampere turns thereof; and if we construct a pole piece that will carry a suitable coil to produce the total ampere turns, we shall closely approximate to the final form.

The reason for the above is simple. The gap space will probably require over 60 per cent. of the total ampere turns. The armature may require 10 per cent. The field magnet will require the balance, or 30 per cent. The provisional length of field magnet circuit will not be in error over 20 per cent., making the possible error on the total ampere turns 20 per cent. of 30 per cent., or 6 per cent.

We will therefore allow 10 per cent. for contingencies, and if we find afterward that we have it to spare, we can either wind a bobbin that will run cooler, which is an advantage, or by another calculation we can reduce the extra space. The latter is rarely advisable. It is always best to have plenty of room on a magnet pole, in case it is desired to wind the frame for other work or a different character of output.

The first problem is the gap space. This will include seven teeth. Fortunately, in a motor the only limitation is mechanical clearance. In a dynamo it would be necessary to proportion the gap space with reference to probable sparking, as the armature reaction tends to reduce the total flux. In the case of the motor the reaction is reversed and can be taken advantage of as indicated. One-tenth of an inch is a suitable clearance, and will avoid mechanical troubles. The tip of a tooth is .82 by 8.7 inches, and the iron face presented to the pole piece is, therefore,

$$.82 \times 8.7 \times 7 = 50 \text{ sq. inches.}$$

This, however, is not the true gap space, because the lines fringe out from the teeth as shown in Fig. 156. The best estimate of the gap space is taken by considering the width of the tooth as the line AB midway in the clearance. The drawing shows the length of this line to be 1.12, and may be obtained accurately by add-

ing to the tooth face half the width of a slot. If the pole piece fluxes seven teeth the true gap space will have an area of

$$7 \times 1.12 \times 8.7 = 68.21 \text{ sq. inches.}$$

It is probable that it will not prove best to extend the polar face to actually cover seven teeth, but undoubt-

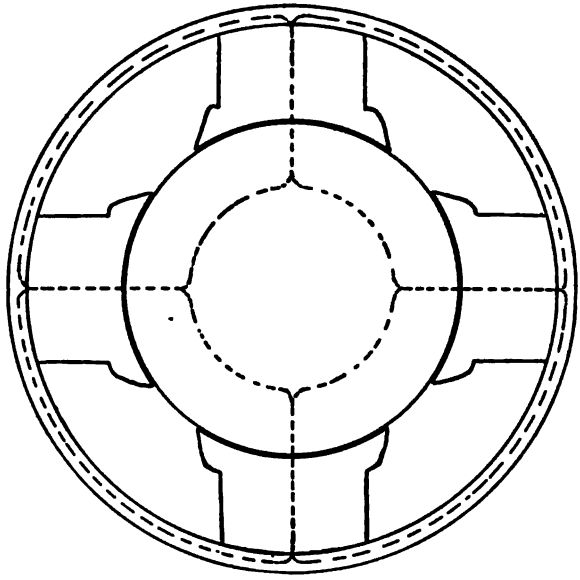

Fig. 157.

edly the flux from one pole will fringe to pass through that number.

In each magnetic circuit there are two gap spaces, making a total thickness of gap space of .2 inch. The density in this gap space is

$$\frac{3,669,000}{68.21} = 53.780 \text{ lines per sq. inch.}$$

At this density it will require

$$53,780 \times .3133 = 16,849$$

ampere turns per inch of length. The gap spaces require, therefore,

$$16849 \times .2 = 3370 \text{ ampere turns.}$$

It will not be advisable to have the motor exceed 24 inches in diameter, for if mounted midway on the car axle with a 33-inch wheel, it will then clear the ground by only 4½ inches. In fact, it will hardly be possible to so arrange the suspension. If we consider the shell section 38 inches long, 24 in length of case, and 7 inches on each side, we shall have a thickness of shell of

$$\frac{29.8}{38} = .784 \text{ inch.}$$

With a 24-inch diameter over all, this leaves 4.1 inches for pole pieces and probably but 3.5 inches for winding space if a pole piece is used.

The length of the path in the steel shell between pole pieces will be one-fourth of a 23-inch circle, which is

$$\frac{23 \times \pi}{4} = 18.06 \text{ inches.}$$

The pole piece itself is 4.1 inches long, it will be of sheets of iron, and should be fluxed to a moderately high working density, so as to render it small and make room for the winding. Still, it must not be run too close to the saturation point for reasons already mentioned; 90,000 lines to the square inch is a good value. Its area, therefore, is

$$\frac{4,769,700}{90,000} = 52.99 \text{ sq. inches.}$$

Its length is already fixed. It should be a little shorter than the armature—8.5 will answer, thereby giving its breadth as

$$\frac{52.99}{8.5} = 6.23 \text{ inches.}$$

The length of the magnetic path through the armature

is equal to a quadrant of the circle midway between the roots of the teeth and shaft plus twice the radial distance of that circle from the roots of the teeth, and is

$$\frac{7.2 \times \pi}{4} + 4.2 = 9.86 \text{ inches.}$$

We are now prepared to calculate the ampere turns necessary for all parts of the magnetic circuit. The reader has probably noted that to get the ampere turns necessary for a portion of the magnetic circuit, the product of the length of the portion, of the flux density, and of a third factor was taken. This third factor was in the case of air .3133. This factor is always the same for air, but for iron it is much less, and varies with the density of flux. It is, in short, .3133 divided by the permeability of the medium at the density under calculation. The product of this factor and the density of flux is known as the ampere turns per inch of length. It is convenient to calculate the ampere turns per inch of length from the permeability curves of the steel and iron that are used in the motor. In fact, it is necessary for accuracy. For our purpose we shall be obliged to take these results from a table for average steel and iron. Such a table is shown on page 191, compiled from one contained in Weiner's "Practical Calculation of Dynamo-Electric Machinery."

The following calculations will now be easily understood:

Ampere turns for steel frame, length 18.06, density 80,000 = 18.06 × 34, ...	= 614.04
Ampere turns for two pole pieces, length 4.1, each density 90,000, = 8.2 × 50.7, . . .	= 415.74
Ampere turns for teeth, length 1.3 each set, density 87,300, = 2 6 × 44, ...	= 114.4
Ampere turns for armature length 9.86, density 50,000. = 9.86 × 9.6, ...	= 94.7
Ampere turns for gap spaces, density 53,790, length .1 each, .2 × 16,849, ...	=3370.
Grand total, ...	4608.88

Ampere Turns per Inch of Length for Various Materials at Different Magnetic Densities.

Magnetic Density. Lines of Force per square inch. ℬ″	Unit Magnetizing Force. Ampere-Turns per Inch Length.					
	Annealed Wrought Iron.	Soft Cast Steel.	Mitis Iron.	Cast Iron containing 6.5 % of Aluminum.	Cast Iron (ordinary).	Air. (=.8133×ℬ″).
2,500	1.2	2	2.5	7	9	783
5,000	1.7	2.	3.4	9.6	13	1,566
7,500	2.1	3.4	4	11.6	16	2,350
10.000	2.2	3.7	4.4	13.5	18.5	3,133
12,500	2.4	4	4.8	15.7	21.3	3,916
15,000	2.7	4.3	5.2	18.2	24.1	4,700
17,500	3.1	4.6	5.6	21	27.1	5,483
20,000	3.5	5	6	24	30.5	6,266
22,500	4	5.4	6.5	27.2	34.5	7,050
25,000	4.5	5.8	7	31	39	7,833
27,500	5	6.2	7.5	35.5	44	8,616
30,000	5.5	6.6	8.1	41.5	50	9,400
32,500	6	7.1	8.7	47.5	57	10,163
35,000	6.5	7.6	9.4	54	65	10,966
37,500	7	8.2	10.1	62	76	11,750
40,000	7.5	8.8	10.9	72	88	12,532
42,500	8	9.4	11.7	83	101	13,315
45,000	8.5	10.1	12.6	95	116	14,100
47,500	9	10.9	13.6	110	136	14,882
50,000	9.6	11.8	14.7	128	160	15,665
52,500	10.3	12.8	15.9	149	189	16.450
55,000	11.1	13.9	17.3	173	222	17,233
57,500	12	15.1	19	200	257	18,016
60 000	13	16.4	21	230	295	18,800
62,500	14.2	17.8	23.2	263	340	..
65,000	15.7	19.3	25.6	300	400	..
67,500	17.5	20.9	28.5	345	470	..
70,000	19.6	22.7	32	400	570	..
72,500	22	24.7	36	460	700	..
75,000	24.7	27	41	525	..	..
77,500	27.7	30	47	600	..	..
80,000	31.2	34	54	700	..	..
82,500	35.2	39	62	..	..	..
85,000	39.7	44	70	..	..	..
87,500	44.7	50	80	..	..	..
90 000	50.7	57	92	..	..	..
92,500	58	65	109	..	..	..
95,000	67	75	131	..	..	..
97,500	78	86	159	..	..	..
100.000	91	100	193	..	..	..
102,500	108	121	245	..	..	..
105,000	137	159	290	..	..	..
107,500	190	227	345	..	..	..
110,000	290	325	410	..	..	..

If the brushes are set near the pole tips they will subtend an angle with the line of theoretical commutation midway between. The slots in the double of this angle contain wires which in a motor *assist* the field magnet to magnetize. In a dynamo they oppose the magnetization. The effectiveness of these slots depends on the winding and the number of neutral slots. To show how they must be taken into account, suppose such an investigation developed that there were 8 such active wires per pole. Their ampere turns would be

$$16 \times 30 = 480,$$

which must be taken from the grand total to get the ampere turns the field coils must supply.

$$4609 - 480 = 4129$$

ampere turns on each magnetic circuit. Each current carries the full current, 60 amperes, giving

$$\frac{4129}{60} = 68.8 \text{ turns.}$$

turns per circuit, or nearly 35 turns per pole piece. A field wire on a railway motor should work at a current density of about 1800 to 2000 amperes to the square inch, although such a density would not be permissible on generators or any other constant full-load work. From this figure we deduce

$$\frac{60}{1800} = .0333 \text{ sq. inches.}$$

as the area of the wire, the nearest B. & S. wire being No. 4. A 35-turn spool would make the best rectangular section in a spool,—7 layers by 5 turns per layer,—but it will be found best to make the coils in as much a pancake or flat form as possible, for the reason that in that form they will best occupy the available space. Nine layers and 4 turns per layer would make

a good form, but the shape cannot be definitely decided till the motor frame has come off the drawing boards, for not until then will the shape of the available space be known. It may be that a special section is necessary. It will be interesting to compute the drop through these coils. The average length of turn will be a rectangle 10.5 by 8.23, for the probable width of the coil will not exceed 2 inches whence we add to the dimensions of the magnet waist correspondingly. The total length of No. 4 wire is, therefore,

$$\frac{(10.5 + 8.23)^2 \times 35 \times 4}{12} = 437 \text{ feet.}$$

At .32 ohm per M feet, corresponding to a temperature of about 200 degrees F., the resistance of the fields will be

$$.32 \times .437 = .1398.$$

The drop through the fields will be

$$.14 \times 60 = 8.4 \text{ volts.}$$

We allowed 45 volts for armature and field drop, and the design develops a drop of 27.15 volts, leaving 17.85 volts extra armature potential. This will produce a slightly higher speed, to avoid which the field flux must be increased. It will be found that one or two extra turns per pole will suffice, and the method of calculation has already been indicated. The watts lost in the field coils will be

$$60 \times 60 \times .1398 = 503 \text{ watts.}$$

If each field coil is 2 inches thick and has lateral dimensions of 12.5 x 10.23, its radiating surface will be

$$(12.5 + 10.23)^2 \times 2 + 2 \times 12.5 \times 10.23 = 347.$$

This estimate includes in the radiating surface the ends of the core which receive heat from the inside of the

coil and dissipate it. Four coils have an area of 1388 square inches, and the watts radiated per square will be

$$\frac{503}{1388} = .362.$$

This corresponds to a rise of about 40 degrees C. in open machines, but in the inclosed machine the temperature would be higher, though it would hardly reach 75 C. Moreover, it is a series bobbin, and carries full current and radiates full energy only at times when the machine is fully loaded. This is not true of shunt bobbins, and it is therefore permissible to construct series bobbins with less radiating surface.

The next thing to determine is the polar arc. We have assumed it to flux seven teeth, which was sufficient for the purposes then in hand, but it must now be determined more accurately. In a dynamo for ordinary work the polar arc would be much shorter than is advisable in railway motor work. The reason for this is found in the fact that, though certain advantages are to be had in the short polar arc, it is necessary to keep down the ampere turns necessary for the air gap to avoid bulky field coils and frame. To do this the air gap must be of large area. Therefore, we will allow just enough space between the tips to allow the coils to commutate, and for this purpose a space of two slots and two teeth will be sufficient. In degrees this is

$$\frac{2 \times 360}{31} = 23.2°.$$

This leaves us a polar arc of

$$90 - 23.2° = 66.8 \text{ degrees.}$$

The design for the field magnet is now provisionally complete. It is as follows: External diameter 24 inches, magnetic waist 8.5 x 6.23, area of shell section between poles 29.8, number of turns per pole 36, size

of wire No. 4 B. & S., length of magnet waist from polar face to shell back 4.1 inches, polar arc 66.8 degrees, density in casing 80,000 lines to the square inch, density in magnet waist 90,000 lines to the square inch, clearance .1 of an inch, polar bore 14.2 inches.

The machine is now ready to go to the drawing board, where it will undergo substantial modifications. The outer shell will be designed with reference to the mechanical features, which will materially alter the shape of the section connecting the poles. The construction of the winding will be selected and all of these features will combine to vary the magnetic data of the motor as it now stands. The shape of the space between the poles is peculiar, and as drawn will require a coil of special section. The outer diameter of the case can undoubtedly be reduced, the magnet waist shortened, and the space for the wire improved. An octagonal form will probably materially help matters. It is probable that it will not be necessary to vary the general dimensions of the armature very much, because it is much easier to produce the desired properties by varying the field. The result will, however, develop a field frame which is tangible, and not a thing of assumption and probability; and it will be possible to wind coils for it which will not widely depart from those which the preliminary calculation has already laid down.

From what has been said it is easy to see that the designer of a railway motor, or indeed of any dynamo-electric machinery, must fortify himself with tables of data, wire tables, tables of current density in coils under various conditions of construction, leakage coefficient tables, and tables and curves of the magnetic properties of iron and steel. All of these data are alike indispensable to the designer. Further than this he

must have an intimate knowledge of the actual performance of machines similar to those he is constructing. There is no successful railway motor on the market to day which was produced with one set of drawings and calculations. The best motors are collections of improvements over an original type as a nucleus.

In conclusion it is necessary to caution the reader that the foregoing discussion is by no means to be considered as complete instruction in the methods of calculating the dimensions and determining construction of a railway motor. It is merely intended to give an idea of how the problem is attacked, and to indicate the class of information which the would-be designer must acquire.

WINDING, SIZE OF		
'ield Wire or Conductor	Armature Wire or Conductor	REMARKS
o. 10 B. & S.	No. 13 B. & S.	Ring armature, 16 turns per section.
Vo. 7 B. & S.	No. 12 B. & S.	" " toothed retained in lower half of frame.
Vo. 4 B. & S.	.34 x .04	" " " wound with flat ribbon.
Vo. 5 B. & S.	No. 12 B. & S.	Smooth body drum.
Vo. 6 B. & S.	No. 10 B. & S.	Eickemeyer drum armature retained in lower half of frame.
Vo. 4 B. & S.	No. 9 B. & S.	" " " " " upper " "
Vo. 9 B. & S.	No. 9 B. & S.	" " " " " lower " "
2 x .060	.075 x 5/8	" " " " " " " "
1¼ x .080	No. 7 B. & S.	Straight out winding " " " upper " "
Vo. 5 B. & S.	No. 10 B. & S.	" " " " " " " " " "
.025 x 1 3/8	No. 9 B. & S.	" " " " " " " " " "
.....	No. 11	Rectangular formed coils.
.....	.....	
.....	.....	One coil cut out, straight out winding.
.....	.....	Three coil per slot, no dead coil straight out winding.
.....	.....	
.....	.....	
.....	.....	
.....	.....	
o. 8 B. W. G.	No. 10 B. & S.	Rectangular formed coil.
180 in diam.	.09 in diam.	Eickemeyer winding.
180 in diam.	.08 in diam.	" "
165 in diam.	.102 in diam.	Straight out winding.
180 in diam.	.102 in diam.	" " "
Vo. 2 B. & S.	No. 7 B. & S.	" " "
Vo. 0 B. & S.	.042 x .6	" " "
o. 000 B. & S.	.073 x .7	" " "
W. G. No. 0000	.045 x .6	" " "
165 in diam.	.09 x .13	Hand wound ring.
.....	.063 x .100	" " "
.....	.....	Ring.
.....	.....	"
.....	.....	"
.....	.....	Drum.
.....	.....	"
.....	.....	"
.....	.....	"
.....	.....	"
.....	.....	" One slot cut out.
.....	.....	" " " "
.....	.....	" " " "
.....	.....	" " " "
.....	.....	" " " "
.....	.....	" " " "
.....	.....	" " " "
.....	.....	" " " "
.....	.....	

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